Universidade Técnica de Lisboa

Faculdade de Motricidade Humana

THE EFFECTS OF PHYSICAL ACTIVITY ON DRIVING ABILITY IN OLDER ADULTS

Dissertação apresentada com vista à obtenção do grau de Doutor no Ramo de Motricidade Humana na especialidade de Ciências da Motricidade

Orientadores

Doutor Mário Adriano Bandeira Godinho
Doutor Filipe Manuel Soares de Melo

Júri

Presidente: Reitor da Universidade Técnica de Lisboa
Vogais: Doutor João Manuel Pardal Barreiros
Doutor Filipe Manuel Soares de Melo
Doutor Duarte Fernando Rosa Belo Patronilho Araújo
Doutor Luís Paulo Brandão Areosa Rodrigues
Doutor Rui Manuel Neto e Matos

JOSÉ FRANCISCO FILIPE MARMELEIRA

2011

Universidade Técnica de Lisboa
Faculdade de Motricidade Humana

THE EFFECTS OF PHYSICAL ACTIVITY ON DRIVING ABILITY IN OLDER ADULTS

Dissertação apresentada com vista à obtenção do grau de Doutor no Ramo de Motricidade Humana na especialidade de Ciências da Motricidade

Orientadores

Doutor Mário Adriano Bandeira Godinho
Doutor Filipe Manuel Soares de Melo

Júri

Presidente: Reitor da Universidade Técnica de Lisboa
Vogais: Doutor João Manuel Pardal Barreiros
Doutor Filipe Manuel Soares de Melo
Doutor Duarte Fernando Rosa Belo Patronilho Araújo
Doutor Luís Paulo Brandão Areosa Rodrigues
Doutor Rui Manuel Neto e Matos

JOSÉ FRANCISCO FILIPE MARMELEIRA

2011

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

The work presented in this dissertation was supported by the Foundation for Science and Technology (Portugal), grant SFRH/BD/31960/2006 awarded to José Francisco Filipe Marmeleira

Este trabalho é dedicado à minha mulher, Zélia,

e aos meus filhos, Beatriz e Miguel

Agradecimentos

Ao Professor Mário Godinho por me ter incentivado e apoiado desde o primeiro esboço de ideias. As suas recomendações foram fundamentais. Um até sempre...

Ao Professor Filipe Melo pela óptima capacidade de orientação e disponibilidade que demonstrou desde o momento em que recebeu este projecto entre mãos.

Aos meus colegas co-autores nos artigos científicos produzidos pela sua contribuição fundamental.

Aos meus colegas do Departamento de Desporto e Saúde da Universidade de Évora, pela camaradagem e óptimo ambiente de trabalho que têm sabido criar. Assim tudo é mais fácil.

À Fundação Portuguesa para a Ciência e Tecnologia pelo apoio financeiro que deu a este projecto. Espero que o trabalho produzido faça justiça ao precioso apoio disponibilizado.

Aos meus Pais. Muito do que sou a eles se deve. Aos meus irmãos, Luís e Fernando, e ao meu amigo Luís Cabanejo, companheiros de uma vida.

A todos os que integraram as amostras nos estudos efectuados.

A todos os que estiveram de algum modo ligados a este projecto.

Abstract

The research described in this thesis aimed to examine the association between physical activity and driving ability in older drivers. Experimental and observational studies were conducted to evaluate the effects of physical activity both in driving-related abilities and on-the-road driving performance. The investigation was grounded mainly in an information processing approach.

Visual attention showed a marked decline with aging. Physical activity levels were positively correlated with visual attention measures, namely processing speed and divided attention.

Driving-related abilities and on-the-road driving tests performance were enhanced with an intervention that used a type of exercise that intended to simultaneously mobilize perceptual, cognitive, and physical abilities. Improvements resulting from the exercise intervention took place on several measures of visual attention, behavioral speed, and multi-task processing. Positive transfer of learning from the exercise program to the driving task was obtained with relatively short time periods of intervention (two to three months). The type of activities to be included in the exercise programs for older drivers should try to target the same cognitive processes that are required in driving.

Results also indicated that the practice of sports on a regular basis for several years has the potential to benefit driving performance. Particularly, tennis playing was associated with better speed of behavior during driving than running. Sports that are more challenging in attentional skills and whose performance is very dependent on the speed at which information is processed, may have a positive influence in several aspects of the driving task.

The role of physical activity for older adults should not be restricted to the promotion of physical fitness, but should also be considered as a means to enhance cognitive functioning. The type of physical activity seems to be an important mediator of such positive effects. Literature reviewed about the effects of training and differential experience on the brain and behavior also supports this potential role of physical activity.

Keywords: driving, aging, physical activity, exercise programs, driving-related abilities, behavioral speed.

Resumo

O trabalho apresentado nesta dissertação teve como principal objectivo o estudo da associação entre a prática de actividade física e a capacidade de condução automóvel em pessoas idosas. Estudos experimentais e observacionais foram efectuados para investigar os efeitos da prática de actividade física em capacidades consideradas importantes para conduzir e no desempenho da condução em estrada. A investigação efectuada teve na psicologia cognitiva o seu quadro teórico de referência.

Foi encontrado um declínio acentuado da atenção visual com o envelhecimento. Foi também estabelecida uma correlação positiva entre os níveis de actividade física e medidas de atenção visual, designadamente de velocidade de processamento e atenção dividida.

Diversas capacidades importantes para conduzir e o desempenho em testes de condução em estrada, beneficiaram da participação num programa exercício planeado para mobilizar simultaneamente capacidades físicas, perceptivas e cognitivas. As melhorias verificaram-se em diversas medidas de atenção visual, velocidade comportamental e no processamento de múltiplas tarefas. Foi possível obter um transfer positivo do programa de exercício para a capacidade de conduzir com relativamente pouco tempo de intervenção (2 a 3 meses). Concluiu-se que o tipo de tarefas incluídas em programas de exercício para condutores idosos deve procurar mobilizar as mesmas funções cognitivas que são requeridas durante a condução.

A prática regular de desporto pode influenciar positivamente a capacidade de conduzir de pessoas idosas. A prática de ténis foi associada a melhores resultados em tarefas de velocidade comportamental durante a condução em estrada do que a prática de corrida de longas distâncias. Os resultados sugerem que os desportos mais exigentes em processos atencionais e cuja performance depende muito da velocidade com que a informação é processada, poderão ter maior influência na realização da tarefa de condução.

O papel da actividade física para pessoas idosas não deve ser apenas restringido à promoção da aptidão física, mas deve ser considerado também como forma de melhorar o funcionamento cognitivo. O tipo de actividade física parece ser um importante mediador nesta associação. A revisão de literatura efectuada sobre os efeitos de programas de treino e da experiência diferencial sobre o cérebro, suporta este papel potencialmente positivo da actividade física.

Palavras chave: condução automóvel, envelhecimento, actividade física, programas de exercício, capacidades importantes para conduzir, velocidade comportamental.

Publications and submitted papers related with this thesis

International journals

Marmeleira, J., Godinho, M., Fernandes, O. (2009). The effects of an exercise program on several abilities associated with driving performance in older adults. *Accident Analysis and Prevention 41*(21), 90-97.

Marmeleira, J., Godinho, M., Malarranha, J., Fernandes, O. (2009). Effects of age in Useful Field of View and Time-to-Arrival. *Advances in Transportation Studies: An International Journal 17,* 29-38.

Marmeleira, J, Godinho, M., Vogelaere, P. (2009). The potential role of physical activity on driving performance and safety among older adults. *European Review of Aging and Physical Activity 6*(1), 29-38.

Marmeleira, J., Melo, F., Tlemcani, M., Godinho, M. (2011). Exercise can improve speed of behavior in older drivers. *Journal of Aging and Physical Activity 19*, 48-61.

Marmeleira, J., Melo, F., Tlemcani, M., Godinho, M., Fernandes, J. Tennis playing, but not running, can enhance speed of behavior in older drivers. *Submitted for publication.*

Marmeleira, J., Ferreira, I,. Melo, F., Godinho, M. Associations between physical activity and driving-related cognitive abilities in older drivers: an exploratory study. *Submitted for publication.*

International Conferences

Marmeleira, J., Ferreira, I., Godinho, M., Fernandes, O. (2007). Time-to-Arrival and Useful Field of View: associations with self reported driving difficulties among older adults. *Proceedings of the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, Stevenson, Washington, pp. 91-97.

Marmeleira, J., Godinho, M., Fernandes, O. (2008). Behavioural speed in older drivers can be enhanced by a specific exercise program. *Book of Abstracts of the 13th Annual Congress of the European College of Sport Science*, Estoril, Portugal, p. 347.

List of Abbreviatons

ACSM	American College of Sports Medicine
AE	Absolute Error
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance (Univariate)
BD	Block Design Test
BDNF	Brain-Derived Neurotrophic Factor
CE	Constant Error
CI	Confidence Interval
CFT	Rey-Osterrieth Complex Figure Test
CG	Control Group
CNS	Central Nervous System
EG	Exercise group
IGF-I	Insulin-like Growth Factor-I
IPAQ	International PA Questionnaire-Short Form
LED	Light Emitting Diodes
MET	Metabolic Equivalent
MMSE	Mini Mental State Examination
η_p^2	Partial Eta Squared
PA	Physical Activity
PC	Personal Computer
PDT	Peripheral Detection Task
RT	Reaction Time
RCT	Randomized Control Trial
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
TMT	Trail Making Test
TTA	Time-to-Arrival
TTC	Time-to-Contact
UFOV	Useful Field of View
UFOV®	Useful Field of View test
VO_{2max}	Maximum Oxygen Uptake
VE	Variable Error
WAIS	Wechsler Adult Intelligence Scale
WHO	World Health Organization

Index of Contents

CHAPTER I

Introduction

Article 1. **The potential role of physical activity on driving performance and safety among older adults**

1. General Introduction

Due to demographic changes and the trends in road accidents, researchers and public health authorities are showing more interest in issues associated with driving performance and safety in older adults.

It is estimated that in the European Union (EU-27), the population aged 65 years and over will continuously increase from the current 86 million to 141 million by 2050; moreover, the longer life expectancy will dramatically increase the numbers of persons reaching very old ages (80+) from 18 million in 2004 to nearly 50 million in 2050 (European Comission, 2008). Statistics also show that the number of crashes per distance traveled is higher in elderly drivers than in all other groups of drivers and that they are very often found to be ‘at fault’ in crashes.

It is expected that older drivers will make up a substantially larger proportion of drivers involved in fatal crashes in the next few decades as a consequence of the increases in the driving licensure in the older population and the consequently larger annual distances covered. Despite this scenario, it seems very unlikely that other transportation alternatives can fully provide the level of mobility that older adults need; being able to drive has a positive influence in the quality of life, even more for those living in small towns and rural areas.

A great deal of the driving-related research has been focused on older drivers′ capabilities. Typically, the main issue has been the elderly drivers’ crash-involvement patterns and/or functional deterioration, and few training strategies have been developed to target driver-related abilities of older drivers. The fact that driving is a complex task involving a large range of skills helps to understand why there has been little research to date on how to develop intervention programs that target driving-related abilities of older drivers.

There are many examples of studies reporting positive effects of physical activity (PA) on perceptive, cognitive, and physical abilities as well as on health conditions. When the positive PA effects are examined closely, an appealing idea emerges: several of the abilities that benefit from PA, such as visual attention, information processing speed, and executive functioning have themselves been associated with driving performance of older adults in the driving-related literature. Despite this potential relationship, few investigations have explored the link between PA and driving-related abilities, and this is even more evident for the group of older drivers. Furthermore, of the interventions directed toward older drivers' capabilities in which PA represents the main strategy, most have focused on only specific abilities related to range of motion and mobility, especially in populations with physical impairments.

2.Objectives and outline of this thesis

The research described in this thesis aimed to examine the association between PA and driving ability in older drivers. There was a particular interest in the effects of specific types of PA, which was evaluated by investigating the influence of a specific exercise program and of regular participation in sports on driving-related abilities and driving performance. The exercise program applied in this thesis was elaborated under the theoretical background that shows (i) a positive relationship between PA and cognitive functioning, (ii) a positive relationship between cognitive training and cognitive functioning, and (iii) potential benefits in cognitive functioning from combining physical and cognitive training. Therefore, the exploration of the effects of specific forms of PA in driving-related abilities and driving performance is a major issue in this thesis.

The main theoretical framework that supports this investigation was the traditional approach to human information processing. The information-processing model begins with the input of stimuli from the environment through the sense organs. Then the input is processed in various stages (perception, response selection and response programming) until an output (e.g., motor activity) is observable. Attention works as a neural filter that allows the performer to focus on what is essential while ignoring less relevant information. Chronometric techniques (e.g., reaction time), which are commonly used in the studies of the information-processing framework, are used in several studies of this thesis.

Following the adopted framework, great importance was given to the effects of PA in brain functions like perception, attention, information processing speed, and executive functioning. Thus, the association between PA and cognitive functioning was a fundamental focus of analysis throughout the thesis. Additionally, the evolution across the lifespan of some driving-related abilities was examined in detail.

In this thesis, driving ability refers to the capacity of the person to drive. It depends on multiple perceptual, cognitive, and physical abilities as well as on health conditions.

Throughout the thesis, definitions of PA and exercise and related concepts were adopted based on the definitions and distinctions for health-related research given by Caspersen et al. (1985). Physical activity refers to body movement that is produced by the contraction of skeletal muscles and that increases energy expenditure. Exercise is a subset of PA that is planned, structured, and repetitive and has as a final or an intermediate objective the improvement or maintenance of one or more components of physical fitness. Physical fitness is a set of attributes that are either health- (e.g., cardiovascular fitness) or skill-related (e.g., reaction time). Because sports are a form of PA that is usually planned, structured, and very often repetitive, sports are considered in this thesis as a form of exercise. Throughout this dissertation, exercise refers to physical exercise except where noted.

This thesis starts with a concise review of the relevant literature (*Chapter 1*) on the factors associated with driving in older adults, and then examines the potential relationships between PA, cognitive functioning, and older drivers' performance. In the present chapter, evidence is provided on why and how PA might have an important role in preserving/enhancing specific driving-related abilities in older adults; a theoretical discussion is presented about the possible mechanisms that underlie the association between PA and driving-related cognitive abilities. *Chapter 1* ends with an already published literature review that summarizes the problem of this thesis. In this article, the driving-related abilities most studied in this thesis are presented; much of them have closer associations with PA and are potentially amenable to modification by its practice.

Chapter 2 includes a description of the methodology used in the present thesis. Special emphasis is provided on the presentation of the exercise program and the experimental methods adopted.

The presentation of the experimental part of this thesis begins in *Chapter 3*. The associations between PA levels and the scores of older drivers on a battery of driving-related cognitive tests are the focus of the first study. In the second study, visual attention and speed perception and their associations with aging are examined.

Chapter 4 presents one of the two intervention studies conducted in this thesis. This study examines the influence of an exercise program designed to specifically enhance perceptive, cognitive, and physical abilities relevant for driving. The exercise program was created based on the scientific evidence that both PA and cognitive training can enhance specific cognitive abilities.

Speed of behavior is examined in two studies presented in *Chapter 5*. In an intervention study and in an observational study, the positive influence of exercise was evaluated in speed variables among older drivers. The type of exercise and its influence in speed of behavior are central to this chapter. In these last studies, the evaluation protocol was performed during on-the-road driving.

Finally, based on these studies, *Chapter 6* discusses, in general, the associations between PA and driving.

3.An overview of factors associated with driving ability in older adults

A literature review by Anstey et al. (2005) gives a good picture of the multiple factors that are associated with driving outcomes (e.g., self-reported crashes/difficulties, crash records or on-road driving measures) in older drivers. These authors concluded that three groups of factors predict driving ability: cognition, visual function and physical function/medical conditions. Significant cognitive factors included measures of attention, reaction time (RT), memory, executive function, and mental status. The study by McKnight and Mcknight (1999) is representative of those reviewed by Anstey et al. (2005). These authors assessed drivers in a variety of driving behaviors during an on-road test and evaluated twenty-two visual, attentional, perceptual, cognitive and psychomotor abilities in which declines have been associated with accidents and advanced age. Significant correlations were found between unsafe driving incidents and deficiencies in attentional (e.g., divided attention), perceptual (e.g., motion detection), cognitive (e.g., memory), and psychomotor (e.g., RT) categories. Another large study evaluated the association between chronic medical conditions, functional, cognitive, and visual impairments and driving difficulty (Lyman, McGwin, & Sims, 2001). It was concluded that a history of falls, visual impairment and some medical conditions were associated with driving difficulties.

Another direction of analysis has been the study of predictors of driving exposure and avoidance among older drivers. Declines in physical and cognitive skills have been linked to increased driving avoidance, decreased driving exposure, and driving cessation. For example, a study with a large sample of 4234 older drivers reported that age, gender, health status, and cognitive functioning had direct effects on both driving exposure and driving avoidance (2006). Stutts (1998) administered a test battery of cognitive and visual function in a sample of 3238 older drivers and found that poorer cognitive abilities (visual attention and executive function) as well as a poorer mental status, were associated with decreased driving exposure (miles driven per year). Lyman et al. (2001) observed that low annual mileage is associated with a history of kidney disease and cognitive impairment; in general, older drivers with a functional impairment (e.g., using stairs and carrying a heavy object), a history of cataracts or high blood pressure reported a low number of days driven per week.

In summary, the literature on older drivers shows that a broad range of perceptual, cognitive and physical abilities as well as health conditions are associated with driving outcomes. It is likely that few strategies of intervention are able to simultaneously target most of these abilities. Physical activity might be one of the few good candidates.

4.Associations between physical activity, cognitive functioning and driving ability in older adults

Physical activity in its multiple forms has the potential to intervene positively in several perceptual, cognitive, and physical abilities as well as health factors. The benefits of PA seem to have a singular expression among the older population because it is well known that aging is associated with noticeable structural and functional changes that can impact activities of daily living. Research on the influence of PA in cardiovascular function, muscular function, body-composition and health conditions (e.g., hypertension and diabetes) is abundant, and its positive influences are now well established (Chodzko-Zajko, et al., 2009). At the same time, the studies of the relationship between PA and cognition are scarce. Nevertheless, the body of work produced in this emergent line of investigation, particularly in the older population, has reported some promising findings. For example, it is now known that the regions of the brain more affected by the aging process (pre-frontal cortices) (West, 1996) are also the ones that seem to benefit more from PA (Colcombe & Kramer, 2003). Moreover, contrary to what was commonly accepted in the recent past among the scientific community, there is now strong evidence that the brain has an important functional and structural reserve that make it very adaptable to the environmental conditions. The neurogenesis phenomenon that can be found in the hippocampus region as a result of exercise is a good example of this innovative field of knowledge (Cotman & Berchtold, 2002).

Several cognitive abilities have been associated with driving performance in older drivers. Thus, although vision, physical performance, and health are associated with driving mobility, cognitive performance may be the strongest predictor of subsequent driving limitations (Ball, et al., 2006; Vance, et al., 2006). Identifying driving-related cognitive abilities that can be changed by PA and examining the mechanisms that support such an effect, will be important for providing relevant data that can contribute to understanding the association between PA and driving. In the next sections, the review of literature is focused on the relationship between PA and cognitive functioning.

4.1.Physical activity, cognitive functioning and aging

There is now strong evidence that exercise and PA have a significant impact on several psychological parameters (Chodzko-Zajko, et al., 2009). Studies have generally shown that older adults who are more physically active exhibit better cognitive performance than do older adults who are less physically active (Baylor & Spirduso, 1988; Dustman, Emmerson, & Schearer, 1994; Etnier, 2008; Spirduso, 1980). Meta-analytic reviews show that the effect size frequently ranges from small to moderate (Colcombe & Kramer, 2003; Etnier, et al., 1997). These benefits of PA include, but are not limited to the following: greater efficiency in information processing (Etnier, et al., 1997; Kramer, et al., 2002), enhancement of attention capacity (Hawkins, Kramer, & Capaldi, 1992; Roth, Goode, Clay, & Ball, 2003), better performance on tasks that demand visual-spatial processing (Shay & Roth, 1992), benefits for executive-control processes (Colcombe & Kramer, 2003) and greater psychomotor speed (Spirduso, 1980). All of these abilities have themselves been associated with driving performance in the driving-related research.

Visual attention is an important ability that benefits from PA. Dustman et al. (1984) showed that a 4 month-long walking program improved the critical flicker fusion threshold of older adults (i.e., the frequency at which a train of flashes is perceived to fuse into a continuous light and is known to be sensitive to hypoxia). A related study (Dustman, et al., 1990) demonstrated that both the critical flicker fusion threshold and the visual sensitivity threshold (i.e., the lowest illumination at which a visual stimulus could be perceived) of aerobically fit young and older men were superior to thresholds of age-matched subjects who seldom exercised. Recently, it was reported that elderly individuals who have expertise in orienteering activities have developed attentional skills that can withstand age-related changes (Pesce, Cereatti, Casella, Baldari, & Capranica, 2007). Roth et al. (2003) concluded that individuals who regularly engaged in PA had significantly better scores than less active individuals on a visual attention test, the useful field of view test (UFOV®, Ball & Owsley, 1993), which has been frequently associated with driving performance in older adults (e.g., Ball, et al., 2006; Vance, et al., 2006). Another study found that aquatic aerobic exercise induced a beneficial influence on attention in older adults during dual-task processing (Hawkins, et al., 1992).

It seems that in older adults aerobic, fitness had a larger impact on tasks that require controlled and effortful processing than on tasks that are executed using automatic processing (Chodzko-Zajko & Moore, 1994; van Boxtel, et al., 1997). Highly fit adults had an advantage in dealing with high-stress and challenging attention-intensive situations (Poon & Harrington, 2006). Furthermore, tasks pertaining to fluid intelligence are more sensitive to physical fitness than those corresponding to crystallized intelligence (Chodzko-Zajko, 1991).

The connection between PA and performance in processing demanding tasks might be relevant for the driving context. Thus, although several vehicle operations become relatively more automatic with experience, driving is a complex task that involves a variety of skills that are called upon simultaneously. Of these skills, one of the most relevant is the acquisition and processing of information and the ability to make appropriate and timely decisions based on this information (Olson & Dewar, 2007). Given that the types of crashes in which older adults are involved often occur in complex traffic situations such as intersections (Mayhew, Simpson, & Ferguson, 2006; McGwin & Brown, 1999), it is reasonable to hypothesize that difficulties occur at the level of executive function (i.e., the planning and decision-making aspect of the driving task) (Anstey, et al., 2005).

Psychomotor speed of fit older adults is faster than the speeds of their less fit age-matched peers, and physical training programs result in the improvement of participants' response speeds (Spirduso, 1980). A greater influence of PA has been shown for choice than for simple reaction tasks among active older adults (Dustman, et al., 1994; Spirduso, 2006). Improvement of information processing speed is especially promising for its potential to impact older adults' functional abilities (Birren & Fisher, 1995; Edwards, et al., 2005). These issues will be further developed in the section dedicated to behavioral speed.

Colcombe & Kramer (2003), in a meta-analytic review about fitness intervention studies conducted from 1966 through 2001, found a clear and significant effect of aerobic fitness training in the cognitive function of older adults, where the effects are largest for those tasks that involved executive control processes. However, it is important to point out that not all longitudinal studies have found positive influences of exercise on cognition (Blumenthal, et al., 1991; Emery & Gatz, 1990; Oken, et al., 2006).

Typically, cross-sectional investigations have provided more convincing evidence for the benefit of PA on cognitive performance, compared to intervention studies (Dustman, et al., 1994; Etnier, 2008). This result brings some problems in the interpretation because the positive effects of fitness on cognitive processes found in cross-sectional investigations may reflect a tendency of the exercisers to be faster and more accurate responders rather than a benefit of aerobic fitness achieved through exercise (Colcombe & Kramer, 2003). In addition, the wide variety of measures used to evaluate cognitive ability, participants' characteristics (e.g., age and a cognitive and health status) and training characteristics (e.g., duration and intensity) makes comparisons between studies difficult (Etnier, 2008; Spirduso, Francis, & MacRae, 2005).

In summary, studies that used cross-sectional and prospective (observational) designs have consistently demonstrated a significant positive association between PA and cognition in older adults. In randomized control trials, the results have been mixed. Nevertheless, when the most well-designed exercise interventions are reviewed using meta-analytic techniques, the results were consistent with a causative relationship between PA and cognition in older adults.

4.2. Mechanisms underlying the relationship between physical activity and cognitive functioning

Potential direct influences of PA on cognitive functioning that have been proposed include cortical structure (neurogenesis and synaptogenesis), cerebral metabolism, neurotransmitters, neurotrophic factors, oxygen availability, glucose regulation, and oxidative stress (Cotman & Berchtold, 2002; Etnier, 2009). Furthermore, it is highly probable that PA also enhances cognition through its effects on mediating variables known to affect cognition (e.g., arousal, self-efficacy, depression, sleep quality, age related diseases like diabetes and hypertension).

Aerobic fitness and cognition

Aerobic fitness is the only intervening variable associated with cognition that has been studied to any extent from a dose-response perspective (Etnier, 2009). *The cardiovascular fitness hypothesis* suggests that the gains in cardiovascular (aerobic) fitness achieved through regular participation in PA mediate cognitive performance benefits (Chodzko-Zajko & Moore, 1994; Etnier, Nowell, Landers, & Sibley, 2006; van Boxtel, et al., 1997). The enhancement of aerobic fitness is thought to be accompanied with changes in the underlying mechanisms such as cerebral blood flow (Endres, et al., 2003; Swain, et al., 2003), brain-derived neurotrophic factor (Vaynman, Ying, & Gomez-Pinilla, 2004; Zheng, et al., 2006) and cerebral structure (Colcombe, et al., 2003; Colcombe, et al., 2006) that have themselves been associated with cognitive performance.

The magnitude of the training effect on older adults' cardiovascular condition differs among studies, and it has been suggested that the amount of physical improvement engendered is related to the degree of change in mental abilities. It has been pointed out (Bashore & Goddard, 1993; Tomporowski, 1997) that studies showing positive effects of exercise in cognition have tended to demonstrate large changes in individual pre- to post-intervention scores for aerobic fitness. Findings from several cross-sectional and other observational studies showed that aerobically fit adults performed better on cognitive tests than did less fit adults (Chodzko-Zajko, 1991; Era, Jokela, & Heikkinen, 1986; Izquierdo-Porrera & Waldstein, 2002; van Boxtel, et al., 1997).

Based on the assumption that aerobic fitness has a greater influence upon cognition among older adults, much of the exercise interventions have been designed to achieve specific amounts of training intensity and volume considered to be necessary to produce significant cardiovascular fitness changes. However, some studies have failed to obtain evidence for the relationship between aerobic training and cognitive function. Panton et al. (1990) assigned older adults (70 to 79 years) to aerobic training, strength training and control conditions. Neither form of exercise was related to subjects' RT or movement speed. Furthermore, an important meta-analysis (Colcombe & Kramer, 2003) found no relationship between the magnitude of improvements in maximum oxygen uptake (VO_{2max}) and the effect of exercise on neurocognitive function. Correspondingly, in the study by Etnier et al. (2006), a meta-regression analysis did not support the *cardiovascular fitness hypothesis*.

Some research has examined the effects of a single session of exercise in mental performance. An acute exposure to a single bout of aerobic exercise can result in short-term improvements in memory, attention, and RT (Colcombe & Kramer, 2003). In a recent study (Kamijo, et al., 2009), twenty-four older and younger males performed a modified flanker task at baseline (no exercise) and after light and moderate cycling exercise while measures of task performance and the P3 component of an event-related brain potential were collected. The results indicated that, for both age groups, the RT following moderate exercise was shorter relative to the other sessions, and P3 latencies following both light and moderate exercise were shorter compared with the baseline session.

Tomporowski (2003) conducted a review of studies that assessed the effects of acute bouts of PA on adults' cognitive performance and concluded that the submaximal aerobic exercise performed for periods of up to 60 min facilitated specific aspects of information processing such as RT, working memory and selective attention. However, extended exercise that led to dehydration compromised both information processing and memory functions. Recently, Chang and Etnier (2009) used an acute bout of resistance exercise (instead of the traditional aerobic exercise) and found a positive impact on automatic cognitive processes and on particular types of executive function in middle-aged adults. A potential mechanism that has been proposed to explain the benefit of acute exercise on cognitive performance includes physiological arousal and plasma catecholamine levels (Tomporowski, 2003).

Cerebral circulation hypothesis

Because oxygen and glucose are not stored in the brain, the vascular system must quickly respond to environmental demands on the central nervous system (CNS) by resupplying activated brain areas with these substances (Dustman & White, 2006).

Despite representing only 2% of the total body weight, the brain uses 20 to 25% of the total body oxygen and 25% of the total body glucose to meet the brain's energy needs and for metabolism and turnover of neurotransmitters (Friedland, 1990). Given this fact, the *cerebral circulation hypothesis* suggest that chronic exercise results in an enhancement of oxygen and glucose transportation to the brain, which results in better cognitive performance because of the increased resources available to the cerebral environment (Chodzko-Zajko & Moore, 1994; Etnier, et al., 2006). This is particularly important for older adults because there is strong evidence that age is inversely related to efficient delivery of blood to the CNS (Slosman, et al., 2001; Takada, et al., 1992). Among the various mechanisms that have been pointed to as being responsible for the age-related decrement in blood flow are an increase in whole-blood viscosity and plasma viscosity, loss of elasticity and progressive fibrosis of cerebral vasculature (Ajmani, et al., 2000; Meyer, Terayama, & Takashima, 1993).

Marks et al. (2000) demonstrated that cerebral blood flow and cognitive function is maintained in aerobically active older adults; McFarland (1963) showed that cognitive decline observed in elderly subjects was similar to impairments seen in younger individuals under conditions of hypoxia. Moreover, it was reported (Rogers, Meyer, & Mortel, 1990) that older adults who are physically active or are still engaged in physically demanding work sustained more constant cerebral blood flow levels than those that who were classified as physically inactive; furthermore, active individuals and workers also scored better on cognitive testing compared to the inactive ones. Rogers et al. (1990) concluded that individuals who retired and led a sedentary lifestyle were at an increased risk of cerebrovascular disease with associated cognitive impairment.

Finally, some studies showed small but significant improvements in cognitive performance (e.g., memory and RT) following supplemental oxygen administration (Moss, Franks, Briggs, Kennedy, & Scholey, 2005; Scholey, Moss, Neave, & Wesnes, 1999) or supplemental glucose administration (Manning, Ragozzino, & Gold, 1993; Manning, Stone, Korol, & Gold, 1998).

Neurotrophic stimulation hypothesis

Research pertaining to mechanisms underlying the effects of PA on brain function has also focused on the related changes in neurotrophins. There are various studies of animal models that have shown that PA induces brain-derived neurotrophic factor (BDNF) and other growth factors consistent with improved neuronal activity, synaptic structure, and neuronal plasticity (Dustman & White, 2006; Winter, et al., 2007). Recent findings in human samples showed that a single bout of exercise can increase plasma BDNF concentration (Winter, et al., 2007); endurance training also led to an increase in both basal as well as the end-exercise BDNF (Zoladz, et al., 2008).

Specifically, BDNF supports the health and functioning of glutaminergic neurons, stimulates neurogenesis and improves learning and mental performance (Cotman & Berchtold, 2002). Neurotrophins are expressed throughout the brain, and some of the highest levels have been found in the hippocampus, an area of the brain important in learning and memory (Cotman & Berchtold, 2002; Neeper, Gomez-Pinilla, Choi, & Cotman, 1995). In addition to increasing the expression of neurotrophins in the brain, exercise increases levels of other types of trophic factors derived from endocrine tissues. It was demonstrated that two weeks of treadmill running enhances plasma levels of insulin-like growth factor-I in rats (IGF-I), which is considered a physiologically relevant neuroprotective factor (Carro, Trejo, Busiguina, & Torres-Aleman, 2001). It has been demonstrated that IGF-I is a potent survival factor for neurons and oligodentrocytes and participates in neuronal growth and differentiation in the brain (Markowska, Mooney, & Sonntag, 1998).

Investigation in animal models demonstrated that IGF-1 levels increase in both the periphery and in the brain after exercise (Carro, Nunez, Busiguina, & Torres-Aleman, 2000); it might be an upstream mediator of BDNF gene regulation, neurogenesis and the ability of exercise to protect the brain from injury (Carro, et al., 2000; Cotman & Berchtold, 2002). Furthermore, it seems that exercise mobilizes gene expression profiles that would be predicted to benefit brain plasticity processes (Cotman & Berchtold, 2002).

The effects of genes encoding neurotrophins and other proteins predict that exercise could regulate downstream anatomical changes that support brain plasticity (Cotman & Berchtold, 2002). More than 40 years ago, the concept of adult neurogenesis (Altman, 1962) was received with skepticism by the scientific community. Presently, it is well established that the mammalian adult brain can produce new neurons (Gould, Beylin, Tanapat, Reeves, & Shors, 1999; van Praag, 2008; van Praag, Christie, Sejnowski, & Gage, 1999). At least one study (Eriksson, et al., 1998) demonstrated that the human hippocampus also retains its ability to generate neurons throughout life. The dentate gyrus, a hippocampal sub-region, is the primary region where the neurogenesis phenomenon takes place (Kempermann, Kuhn, & Gage, 1997; Kramer, Bherer, Colcombe, Dong, & Greenough, 2004); the hippocampal region is associated with memory and learning. Recent studies have suggested that neurogenesis can also be found in neocortical association areas such as the prefrontal and posterior parietal cortices of nonhuman primates (Gould, Reeves, Graziano, & Gross, 1999; Gould, Vail, Wagers, & Gross, 2001). Nevertheless, other studies using similar methodological approaches have not been able to substantiate cortical neurogenesis in the frontal and prefrontal cortices of adult nonhuman primates (e.g., Kornack & Rakic, 2001).

Physical activity is one of the factors that positively affects adult neurogenesis (Kramer, et al., 2004; van Praag, et al., 1999). Other factors include stress, aging, and environmental enrichment (Gould, Woolley, & McEwen, 1990; Kempermann, et al., 1997). Research conducted with animals found that exercise characterized by unskilled motor movements increased capillary density without a significant change in synapse number, whereas motor skill learning induced synaptogenesis in higher-order brain regions involved in motor learning with no change in capillary density (Black, Sirevaag, & Greenough, 1987; Kleim, Lussnig, Schwarz, Comery, & Greenough, 1996; Kleim, Vij, Ballard, & Greenough, 1997). Other studies were able to establish a positive correlation between running and neurogenesis in animals, raising the hypothesis that the new hippocampal neurons may partly mediate the improved learning associated with exercise (van Praag, et al., 1999).

Colcombe et al. (2006) showed that regular aerobic exercises may cause an increase in regional gray matter volume in older adults. Significant increases in brain volume, in the both gray and white matter regions, were found as a function of fitness training for subjects who participated in the aerobic fitness training but not for subjects who participated in the stretching and toning (nonaerobic) control group. However, despite the enthusiastic recent research in adult neurogenesis, it is important to point out that the functional significance of this phenomenon remains elusive.

Neurotransmitter systems

The degeneration of neurotransmitter systems, primarily the dopaminergic system, may contribute to age-related gross and fine motor declines as well as to higher cognitive deficits (Seidler, et al., 2009). Age-related working memory impairment was related to reduced prefrontal cortex dopaminergic transmission caused by decreased dopamine synthesis in the prefrontal termination region (Mizoguchi, Shoji, Tanaka, Maruyama, & Tabira, 2009).

Directly testing of neurotransmitters changes in humans is not possible. As a result, animal studies have been carried out to support the claim that exercise induces changes in brain concentrations. Researchers have focused their efforts on the study of noradrenaline and dopamine; for both, the results have been far from unequivocal, although there appears to be more consistency for dopamine (McMorris, 2009). Altough early animal studies (e.g. Brown, et al., 1979) demonstrated increases in brain concentrations of catecholamines during exercise, more recent studies using different procedures (microdialysis) have not entirely corroborate these reports.

There is evidence of increased dopamine concentrations during and following acute exercise and as a result of chronic exercise. Research on acute exercise has demonstrated increases particularly in the brainstem and hypothalamus (Meeusen et al., 1996, 2001). There seems to be a “threshold speed” above which neurotransmitter release begins (Hattori, Naoi, & Nishino, 1994; Meeusen, Piacentini, & De Meirleir, 2001). Chronic exercise shows region-specific effects with increases in the hypothalamus and midbrain concentrations but decreases in the prefrontal cortex, hippocampus and striatum (Meeusen, et al., 1997).

In general, studies have shown either a decrease or no significant effect of chronic exercise on noradrenaline concentrations in the whole brain, although there are some regional variations (especially in the hypothalamus) (Meeusen, et al., 2001; Meeusen, et al., 1997). There is, however, unequivocal evidence for increased catecholamine turnover in the brain during exercise (McMorris, 2009). Increased concentrations of catecholamine metabolites (the by-products of catecholamine synthesis and usage) have been found in the brain during and following acute exercise. As such, it would be reasonable to state that exercise induces increased catecholaminergic activity in the brain during activity (McMorris, 2009).

Taken together, animal studies have provided evidences that the central dopaminergic, noradrenergic, and serotonergic activity, release, and metabolism are influenced by exercise (Meeusen, 2005). The results seem to be more consistent for neurotransmitter responses during exercise than for long-term adaptations.

Nevertheless, the studies in this research area are scarce and have been marked by technological limitations (for example, measurements in the synapses are not yet possible). An important question to be answered is how changes in the synthesis and metabolism of neurotransmitters as a result of exercise can influence cognition. One of the possible answers is that it might follow an indirect pathway: neurotransmitter changes may underlie most of the impact of exercise in reducing depressive symptoms both in healthy and clinical populations (Dratcu, 2009). The associations between depression and cognitive decline have been observed in several studies of elderly populations (e.g., Sachs-Ericsson, Joiner, Plant, & Blazer, 2005).

Cognitive energetics, arousal and self-efficacy

An interesting view about the benefits from both mental and physical training was provided by Dienstbier (1989, 1991). He hypothesized that declines in mental and physical health, regardless of age, result from insufficient physical and mental challenge and that controlled and repeated challenge, either physical or mental, builds up the resources and the "mental toughening" needed to meet environment demands and cope with stress. Increased peripheral and central catecholamine capacities are pointed to support this behavioral change. Dienstbier (1989) reports data from both non-human and human studies that better performances across a variety of tasks appear to be associated with increased catecholamine levels (adrenaline, noradrenaline, and dopamine) and quicker return to baseline rates following stressful manipulations.

Extending this perspective, Tomporowski (1997) considers that older adults' responses to challenging tasks are predicted to lead to both short-term and long-term physiological benefits as the increase in the levels of arousal and energy set the stage for individuals to meet and overcome task demands. Related to this framework is the dimension of demanding exerted by the training tasks (both physical and cognitive).

Arousal is an important construct in the domain of motor learning. It is often thought of as an abstract construct encompassing a variety of processes, including those that mediate alertness and wakefulness, and has been defined in terms of autonomic responses (e.g., changes in heart and breathing rate), neurophysiological responses (e.g., activity in the reticular formation), and/or behavioral responses (e.g. increased attentiveness) (Green & Bavelier, 2008). The well known Yerkes–Dodson law (Yerkes & Dodson, 1908) predicts that learning is an inverted U-shaped function of arousal level.

Task difficulty is also interconnected with the notion of arousal (Gellatly & Meyer, 1992). Tasks that are much too difficult or much too easy will lead to lower levels of motivation and thus substantially reduced learning. The learning rate would be at a maximum when the task is challenging yet still doable (Green & Bavelier, 2008).

Frequently, older adults develop low perceptions of their control and competence, with negative consequences on their motivation (McAuley & Elavsky, 2008; Tomporowski, 1997). Thus, the benefits of physical and mental training might reside more in changed beliefs than in cognitive abilities per se (Cavanaugh, 1990). Older adults' perceptions of competence are known to play a role in explaining age-related differences in cognitive test performance.

One important aspect of the perceived control over one's life is the construct of self-efficacy. Self-efficacy is concerned with the individual's beliefs in his or her capabilities to execute necessary courses of action to satisfy situational demands (Bandura, 1986). Self-beliefs of efficacy can enhance or impair performance through their effects on the cognitive, affective, or motivational intervening processes; more efficacious individuals approach more challenging and varied tasks (Bandura, 1989). According to McAuley & Elavsky (2008) mastery experiences (performance accomplishments) are the most potent source of self-efficacy beliefs, often providing objective evidence relative to what constitutes a success or a failure. Mastery experience are interconnected with task difficulty level, level of effort expended in the task, whether assistance is provided by others, and the sequencing of successes and failures (McAuley & Elavsky, 2008)

5. Effects of training and differential experience on brain and behavior

5.1.Cognitive complexity and cognitive training

It is widely believed that keeping mentally active will prevent age-related mental decline (Salthouse, 2006). This is frequently known as the "use it or lose it" hypothesis, and it predicts that engagement in intellectual, social, and physical activities offers protective benefits from age-related cognitive decline and lowers dementia risk (Bielak, 2010); from a neurobiological perspective, this notion states that the use of neurons and neuronal networks prolongs the efficiency of CNS activity during life (Slegers, van Boxtel, & Jolles, 2006; Swaab, 1991).

It has been hypothesized that the cognitive complexity level of everyday tasks (work and leisure-time activities) could affect older people's intellectual functioning. A recent review of the literature has supported the idea that an association exists between the elderly individuals' levels of intellectual functioning and the intellectual demand of the tasks they perform (Schooler, 2009). This hypothesis is supported by some important data that showed a positive association between cognitively demanding work conditions and intellectual flexibility (Kohn & Schooler, 1983; Schooler, 2009). Bosma et al. (2003) concluded that providing work-related cognitive stimuli and challenges for poorly educated people might help in reducing the age-related gap in cognitive decline between poorly and highly educated people. Moreover, research has also provided evidence that the intellectual demand level of occupational conditions can affect the intellectual demand level of leisure-time activities experiences (Schooler, 2009). Despite these promising findings, given the lack of longitudinal experimental studies, it is difficult to establish a cause-effect relationship between experiencing complex environments and intellectual functioning. Thus, positive correlations could reflect the psychological effects of complex environments or the fact that individuals with high intellectual functioning tend to select or are selected into such environments (Schooler, 2009)?.

Various longitudinal studies have also provided support to the "use it or lose it" hypothesis. Zunzunegui et al. (2003) reported that few social ties, poor integration, and social disengagement are risk factors for cognitive decline among community-dwelling elderly persons. Others have found that higher frequencies of participating in activities like reading, playing chess, and completing crosswords were related to slower declines in perceptual speed (Ghisletta, Bickel, & Lovden, 2006).

The benefits of participating in more demanding lifestyle activities appear to be greater in later adulthood compared to young or mid-old adulthood (Hultsch, Hammer, & Small, 1993). For example, for individuals between the ages of 75 and 94 years, there were more and stronger correlations between activity and cognitive speed for both baseline and 6-year change measures than in those between the ages of 55 and 74 years (Aartsen, Smits, van Tilburg, Knipscheer, & Deeg, 2002).

Mohammed et al. (2002) concluded that the findings on the neurobiological research of environmentally induced changes in the brains of aged organisms are compatible with the notion of “use it or lose it”. Schooler (2009, p. 32), in a recent review about this issue, has a similar opinion: “Even in old age, working out on a regiment of substantively complex tasks appears to build the capacity to deal with the intellectual challenges that complex environments provide”.

There is a growing body of evidence of positive effects of programmed cognitive stimulation at a behavioral and functional level. In a frequently cited work, Ball et al. (2002) enrolled 2800 subjects in training programs for memory function, speed of processing, or reasoning. Subjects were trained over a six-week period and received 10 one-hour sessions overall; 4-session booster training was offered to a large part of the sample 11 months later. Ball and colleagues showed benefits of training on the specific ability trained (speed of processing and reasoning), but not transfer to novel tasks.

Results from a recent study (Tranter & Koutstaal, 2008) provide evidence that even brief periods of increased cognitive stimulation can improve older adults' problem solving and flexible thinking. In this study, the training program have provided opportunities to engage in a wide range of novel problem-solving and creative activities during 10 to 12 weeks. When the additional effort required by more cognitive effort tasks is rewarded (for example, by the beneficial effect associated with learning a new skill) it is possible that people become more motivated to further develop these capacities.

The individual functional baseline level may influence the benefits of activity engagement, and several studies that have failed to find significant relationships between activity and cognition, involved participants with high education and intelligence (e.g., Christensen, et al., 1996; Salthouse, Berish, & Miles, 2002). According to Bielak (2010) a possibility exists that highly educated adults derive a smaller cognitive gain from activity because they already have already accumulated substantial cognitive reserve from education. Even so, cognitive gains have also been found in highly educated samples (e.g., Bielak, Hughes, Small, & Dixon, 2007; Hultsch, Hertzog, Small, & Dixon, 1999).

Despite the encouraging results of the cognitive training literature, it is important to note that little is known about what duration and intensity of an activity is required to benefit cognition. Furthermore, the diversity of the content of cognitive programs make it difficult to establish a standard body of activities. The influence of cognitive training programs in the context of driving will be discussed later.

5.2.Enriched environments

Environmental enrichment is an experimental model in which animals are housed in conditions that potentiate social interactions and sensory and motor stimulation (Rosenzweig & Bennett, 1996; Segovia, del Arco, & Mora, 2009). The “use it or lose it” hypothesis is also supported by this research paradigm, which provides evidence that stimulating and challenging habitats are beneficial to the cognitive functioning of laboratory animals (Black, et al., 1987; Kleim, et al., 1996; Vaynman, et al., 2004). Thus, as a result of living in an enriched environment, the brains of animals undergo molecular and morphological changes leading to improvements in learning and memory. Mediating mechanisms engendered by enriched environments and training in behavioral tasks includes increased dendritic branching and synaptogenesis, changes in supportive glial cells, addition to the brain’s capillary network, the development of new neurons, and a cascade of molecular and neurochemical changes (Kramer & Morrow, in press).

Some authors support the hypothesis that environmental enrichment and exercise affects brain neuronal circuitry in similar ways, including the regulation of growth factors, neurogenesis and structural changes, which regulate behavioral plasticity (Biernaskie & Corbett, 2001; Cotman & Berchtold, 2002; van Praag, Kempermann, & Gage, 2000). Evidence exists that environmental enrichment and exercise affect different phases of the neurogenic process in distinct ways: the former seems to increase the likelihood of the survival of new cells, whereas the latter increases the level of proliferation of progenitor cells (Olson, Eadie, Ernst, & Christie, 2006). Nevertheless, clear conclusions on this issue are difficult to make because in some studies more opportunities for PA are also included as part of the environmental enrichment (e.g., Kempermann, Kuhn, & Gage, 1998).

Important research has been conducted on the influence of different types of PA on the brain. For example, Klintsova et al. (1998) reported that while motor skill training (obstacle course) enhanced performance on a number of subsequent behavioral tasks such as parallel bars, rope climbing, and rotarod, motor activity alone such as walking in a closed alley had little effect on performance. In a study by Black et al. (1990), the cerebellar cortex in motor learning was investigated by comparing the paramedian lobule of adult rats given difficult acrobatic training to those of rats that had been given extensive physical exercise or had been inactive (the cerebellum is activated during limb movements used in both acrobatic training and physical exercise). The number of synapses per neuron in both the motor and cerebellar cortices was greater in rats trained on the acrobatic course than animals from the exercise or inactive groups. No significant difference in synapse number or size between the exercised and inactive groups was found. This result indicates that the specific motor learning required of the acrobatic animals, not the repetitive use of synapses during physical exercise, generated new synapses in the cerebellar cortex. In contrast, exercised animals had a greater density of blood vessels in the molecular layer than did either the acrobatic or inactive animals, suggesting that increased synaptic activity elicited compensatory angiogenesis. Thus, it appears that learning, not merely neural activity, is required to induce synaptogenesis (Markham & Greenough, 2004).

In a recent analysis of the latest research on the impact of motor activity and inactivity on the brain, Woodlee and Schallert (2006) concluded that, in general, increases in either unskilled or skilled activity seem to cause changes in brain vasculature, trophic-factor expression, and (in the case of skills training) the number and structure of synapses in certain areas. Later in this thesis, this theme will be addressed again and will help to establish a framework to examine the potential effects of different type of exercise on driving-related abilities.

It is important to point out that there is evidence that some brain-cellular changes seen in normal aging can be slowed or reversed with exercise. Thus, Van Praag, Shubert, Zhao, and Gage (2005) found that, even when exercise was not started until late in a rat’s life, voluntary wheel running reduced age-associated declines in the neuronal proliferation and cell number in the hippocampus, as well as improving performance in spatial-navigation tasks.

Environmental enrichment research has been mostly done on rodents, but similar effects have been documented in primates (Kozorovitskiy, et al., 2005). Direct research in humans has been limited because it require histological study of the brain. However, a study that involved the autopsy of human brains (Jacobs, Schall, & Scheibel, 1993) was consistent with the environmental enrichment research results in animals and suggested that dendritic systems in humans function as a sensitive indicator of an individual's (a)vocational activities (education had a consistent and substantial effect such that dendritic measures increased as educational levels increased).

Taken together, these findings provide a biological explanation for the positive effects produced by physical and mental activity on different cognitive functions in the elderly and also for the reduction in the risk of developing neurodegenerative disorders (Churchill, et al., 2002; Segovia, et al., 2009).

6.Transfer of learning

In the context of motor learning, Magill (2003) characterized the transfer of learning as the influence of previous experiences in a new context or on learning a new skill. It is commonly known that the transfer of learning is associated with the similarity of the tasks being considered. Thorndike and Woodworth (1901) considered that “identical elements” must be present in the learning and application situation for transfer to occur. Judd (1908) put forward the idea that general principles, rules and theories could form the basis for the transfer of learning. He was a proponent of the idea of the transfer of generalizations to new situations. As a result of experience, the individual reaches some conclusion or generalization, which is applied to oncoming experiences (Mangal, 2007).

Several types of transfer have been described in the literature. *Positive vs. negative* transfer indicates whether the learning is enhanced or suffers a negative impact by prior experiences. *Near vs. far* transfer refers to the transfer of learning when the task and/or context change slightly but remain largely similar or learning occurs with related but largely dissimilar problems. *Low-road vs. high-road* transfer expresses a distinction between the transfer of well-established skills in an almost automatic fashion from the transfer that involves deliberate effortful abstraction and a search for connections between contexts.

Magill (2003) considers that there are two main hypotheses to explain why transfer of learning occurs. In the tradition of the “identical elements theory” of Thorndike, both hypotheses consider the idea of similarities between situations. The *skills components hypothesis* assumes that the transfer of learning occurs because the components of the skills and/or the context in which the skills are performed are similar. A “component part” could be any observable movement part of a skill (its kinematics characteristics) or can be related to “task-specific coordination dynamics”.

The *similarity of the cognitive processes hypothesis* posits that transfer occurs primarily because of similarities between the amount and types of cognitive processes required by the two skills or two performance situations. For positive transfer to occur between the training and transfer tasks they must involve the same types of mental activities (Magill, 2003) (e.g., engaging in problem-solving activity, rapid decision-making, application of rules, attention control, or the simultaneous performance of two or more tasks). Within this framework the training and the transfer tasks do not need to have similar movement components: the critical feature is the similarity between the cognitive processing demands of the training task and those of the transfer task.

There are only a few studies of positive transfer of learning in the scientific literature on motor behavior. In fact, a specificity of learning phenomenon occurs very frequently in which improvement is observed only in the trained task, with little to no transfer of learning being observed even for very similar untrained tasks (Green & Bavelier, 2008; Schmidt & Lee, 2005). Cognitive training studies consistently demonstrate improvements in several abilities such as attention, memory, and reasoning, but show that training differences are typically specific to the ability trained (Ball, et al., 2002).

Despite this trend in the transfer-related literature, some training paradigms have been established in which learning seems more general. These learning paradigms are typically more complex than laboratory manipulations and correspond to real-life experiences, such as action video game training, musical training, or athletic training (Green & Bavelier, 2008).

Green and Bavelier (2003) showed that action-video-game playing is capable of altering a range of visual skills. They detect significant changes in visual attention in habitual video-game players compared with non-video-game players; furthermore, non-players trained on an action video game show marked improvement from their pre-training abilities. The positive influence of video games were found in the abilities to (i) detect more number of visual items in a brief glance, (ii) to locate targets amongst distractors in the peripheral vision, and (iii) to report a second target that appears a few hundreds of milliseconds after the onset of the first target. Green and Bavelier hypothesized that by forcing players to simultaneously juggle a number of varied tasks (detecting new enemies, tracking existing enemies and avoiding getting hurt, among others), action-video-game playing pushes the limits of different aspects of visual attention. It led to detectable effects on new tasks and at untrained locations after only 10 days of training. Changes in the speeded perceptual processes and/or better management of several tasks at the central executive level probably contributed to the reported enhancement.

In a controlled clinical trial, older adults randomized to speed-of-processing training experienced improvements in UFOV® performance that were maintained over a 5-year period relative to controls (Willis, et al., 2006). This promising type of training is based and most similar to the assessment test UFOV® (Ball & Owsley, 1993). The training protocol is applied in computer screens and uses three levels of approach focusing the ability to identify visual information quickly in a central, divided or selective-attention format. In level one, a central stimulus is presented at a progressively faster speed until the participant's threshold to identify it is lowered to a minimum (17 ms). The second level of training required the participant to perform the centrally located identification task and also to locate a peripheral target. Different presentation speeds (progressively faster, with a minimum presentation time of 40 ms) are used, and the stimulus at the periphery is presented at different eccentricities (maximum is 30º). The third level of training required the participant to perform the identification task and locate the peripheral target embedded among distractors. Training is provided in the same manner as described for the second level.

Results by Edwards et al. (2005) indicate that the speed-of-processing training not only improves processing speed, as indicated by performance on the UFOV®, but also transfers to certain everyday functions, as indicated by improved performance on timed instrumental activities of daily living (e.g., quickly finding a telephone number). Furthermore, it was shown that the processing speed is protective against declines in health-related quality of life across 5 years (Wolinsky, Unverzagt, Smith, Jones, Stoddard, et al., 2006; Wolinsky, Unverzagt, Smith, Jones, Wright, et al., 2006) and against mobility declines among older drivers (Edwards, Myers, et al., 2009).

There is some variability in the duration of the speed-of-processing training probably due to the different sample characteristics (e.g., different performance levels at baseline). It was reported that 10 one-hour sessions were held during 5 weeks (Edwards, Myers, et al., 2009), that the average number of training trials completed was 1040 (SD 504, range 368-3104) (Roenker, Cissell, Ball, Wadley, & Edwards, 2003), and that the training intervention was 10 sessions (Wolinsky, Unverzagt, Smith, Jones, Wright, et al., 2006) or 10 sessions with an additional "booster training of 4 sessions" (Willis, et al., 2006). It is important to note that the speed-of-processing training has been shown to be valid mainly for the older adults who are at a higher risk or already have some kind of functional deficit, such as useful field of view (UFOV) deficits. Near-transfer of speed-of-processing training (i.e., to tasks that rely heavily upon rapid information processing and visual search) has been much more evident than transfer to other cognitive domains (measures that are not considered to be pure markers of the speed construct itself, like executive function and memory) (Edwards, et al., 2002; Edwards, et al., 2005).

Research has also shown that transfer of learning can occur on dual-task conditions using a variable priority training technique (Kramer, Larish, & Strayer, 1995; Kramer, Larish, Weber, & Bardell, 1999). In this procedure, participants are required to vary their response priorities between the two tasks, whereas in the more typical fixed priority condition, attention was given equally to the tasks. The greater improvement obtained under the variable priority condition suggests that learning to modulate attention may be crucial in the acquisition of task coordination skills. Bherer et al. (2005) observed that even when two tasks require similar motor responses, both older and younger adults can learn to perform a visual discrimination task and an auditory discrimination task faster and more accurately. Moreover, the improvement in performance generalized to new task combinations involving new stimuli. More recently, the same research group extended this findings to a dual-task condition that involved two visual tasks requiring two motor responses (Bherer, et al., 2008). Thus, dual-task skills can be substantially improved in older adults and cognitive plasticity in attentional control is still possible in the elderly.

6.1.Tranfer of learning in sports

Transfer of training effects from a virtual training task to game performance has been found in tennis players. In one study (Williams, Ward, Knowles, & Smeeton, 2002) recreational tennis players engaged in a perceptual laboratory-based training that included viewing film clips of expert tennis player executing specific shots from an on-court perspective. Players who received perceptual training improved their performance on laboratory- and field-based tests of anticipation when compared with matched placebo and control groups that did not receive any instruction regarding expert performance strategies. In another similar study (Smeeton, Williams, Hodges,

& Ward, 2005) the tennis player's RT and accuracy were tested for various tennis shots in a laboratory setting and on the court both before and after training. Training involved responding to tennis shots projected in a laboratory. Relative to the control group, the trained participants improved in performance in the lab and on the court.

A recent study (Lobjois, Benguigui, Bertsch, & Broderick, 2008) examined the relationship between age and collision avoidance skill (time-to-collision judgments) and whether playing tennis affects this. Three age groups (20 to 30, 60 to 70, and 70 to 80 years) of tennis players and non-players were included. The results showed a beneficial effect of playing tennis on the collision avoidance skill of 70- to 80-year-old tennis players.

Research conducted among university basketball players aimed to determine whether training with a visual perceptual strategy called the quiet eye (defined as the player's final fixation on the hoop or backboard prior to the shooting action) would improve the free throw accuracy over two seasons of competition (Harle & Vickers, 2001). Results showed that the team that received the quiet eye training throughout the seasons improved more than the control teams in their free throw shooting accuracy during the second season.

Recent literature has verified the usefulness of PA and cognitive training as means to enhance perceptual and cognitive abilities that have been associated with driving performance. In this context, it is interesting to examine if the combination of fitness and cognitive training that results from years of extensive sports training also results in superior performance on tests of cognitive processes. Like in other domains, the high level of performance of experts in sports performance is assumed to be largely achieved by extensive practice and not simply innate talent (Salthouse, 2006).

An important question is if there are both sport-specific and sport-general cognitive enhancements from competitive sport training. In this context, two research perspectives on sport expertise have been followed. The expert performance approach studies the athlete under a sport-specific context; tasks used under this approach present sport-specific displays and are designed to simulate the sport context. The cognitive component skills approach studies the relationship between basic measures of cognitive ability and sport expertise; this kind of research separates the testing environment from the sport context.

Within the expert approach, there is consistent evidence of contextual perceptual and cognitive advantages for sport experts. In a meta-analytic review

(Mann, Williams, Ward, & Janelle, 2007) focusing on perceptual-cognitive skills in sports it was concluded that experts were better than nonexperts in picking up perceptual cues (higher response accuracy and lower response time) and that experts used fewer fixations of longer duration, including prolonged quiet eye periods, compared with non-experts. A literature review (Williams, Davids, & Williams, 1999) concluded that experts showed various advantages compared with non experts: they were faster and more accurate in recognizing patterns of play; they detected and located objects of relevance in the visual field quickly and accurately; they were better at anticipating the actions of their opponents based on advance visual cues, and they made more appropriate tactical decisions. Finally, a review of reviews (Voss, Kramer, Basak, Prakash, & Roberts, 2009) noted that, overall, research has found that experts performed better than non-experts on sport-specific tests of declarative memory, attention and attentional allocation, perception or information pick-up, anticipation and decision-making skills and memory for sport-specific environmental information.

From the cognitive component perspective, results have been more diverse. Voss et al. (2009) reported that athletes performed better on measures of processing speed and a category of varied attentional paradigms (e.g., divided attention) and that athletes from interceptive sport types and males showed the largest effects. It is very interesting that athletes in interceptive-dominant sports (e.g., squash and tennis) had faster response times than athletes in an 'other' category which included closed, self-paced sports such as golf and swimming. Castiello and Umiltá (1992) investigated whether professional volleyball players showed changes in the orienting of attention along horizontal and vertical axes and concluded that compared with controls the volleyball players shifted attention faster along either the horizontal or the vertical meridian.

Ando et al. (2001), after comparing 6 soccer players and 6 nonathletes, concluded that the former group showed shorter premotor times during central and peripheral visual RT tasks than the latter group, suggesting that the soccer players are better able to respond quickly to a stimulus presented at peripheral as well as central positions. Recently, it was reported that elderly individuals who had expertise in orienteering activities have developed attentional skills that withstand the age-related changes of visual attentional focusing (Pesce, et al., 2007). Nevertheless, several studies have failed to find differences between experts and non-expert athletes in cognitive measures (Lum, Enns, & Pratt, 2002; McAuliffe, 2004). Helsen and Sarkes (1999) have not found advantages for semi-professional soccer in various non-specific abilities, including processing speed (simple RT, peripheral RT, visual correction time) and optometric measures (static, dynamic and mesopic acuity). The horizontal peripheral range of the visual field was the only measure that presented better results among the sport experts.

Considering the mixed results found in the literature, it is necessary to continue to investigate what cognitive abilities subserved by the CNS are malleable in response to the participation in sport and which ones may play a more general rather than specific role in sport expertise. An important theme is if and how different sport types can impose characteristically different sets of mental demands upon the practitioner to target different perceptive and cognitive abilities. Additionally, it is important to distinguish between experts, who are defined on the basis of their very high level of performance in a specific domain, and people who merely have considerable experience with an activity.

One major question that remains to be answered (and is intrinsically connected to the subject of the present thesis) is whether enhanced cognitive skills as a result of sport/exercise might transfer to other tasks of everyday living such as paying attention throughout a classroom lecture, being productive in a noisy workplace, or driving safely on congested roads and intersections (Voss, et al., 2009).

6.2.Transfer of learning in driving

In the driving-related literature, there are some examples of training programs that show different levels of effectiveness, especially in the extent of transfer to on-the-road driving. Perhaps the more successful examples come from speed-of-processing training.

In a study by Roenker (2003), elderly adults were assigned to a group that participated in a speed-of-processing training program, a group that participated traditional driver training program performed in a driving simulator, or a low-risk reference group. Participants were evaluated in a driving simulator and completed an open-road driving evaluation. Speed-of-processing training, but not simulator training, improved the UFOV® test performance, transferred to some simulator measures, and resulted in fewer dangerous maneuvers during the driving evaluation.

The simulator-trained group improved on two driving performance measures: turning into the correct lane and proper signal use. Similar effects were not observed in the speed-of-processing training or low-risk reference groups. While encouraging, the study failed to find similar effects in 7 composite driving measures, such as use of turn signals, lane changing, speed control and stopping position.

Ball et al. (2007) combined data from six studies, all using the same speed-of-processing training program, to examine the mechanisms of training gain and the impact of training on cognitive and everyday abilities of older adults. The results indicated that the training produces immediate improvements across all subtests of the UFOV® test performance, particularly for older adults with baseline speed of processing deficits. Age and education had little to no impact on training gain. Participants maintained benefits of training for at least 2 years, which translated to improvements in everyday abilities, including efficient performance of instrumental activities of daily living and safer driving performance.

A recent study concluded that speed-of-processing training might delay driving cessation among older drivers with speed-of-processing difficulties (Edwards, Delahunt, & Mahncke, 2009). Sifrit et al. (2003) conducted a study to determine whether visual attention skills of older drivers (60-81 years) were amenable to training. Following an initial visual attention assessment, 20 participants assigned to the training group completed five 30-minute visual attention training sessions. The remaining 20 participants were assigned to the control group. The results indicated that following the training interval improvements in selective and divided attention occurred for participants with initially poor selective/divided attention but not for those with initially high selective/divided attention. The same research group found that speed-of-processing training improved the number of hazards detected in a simulated driving task (Sifrit, Chaparro, Groff, & Stumpfhauser, 2001).

Cassavaugh & Kramer (2009) trained older adults on single and dual tasks of attention, working memory and manual control and reported a positive transfer for performance on a driving simulator. Marottoli et al. (2007a) sought to determine whether a multicomponent physical conditioning program targeted to axial and extremity flexibility, coordination, and speed of movement could improve driving performance among older drivers. Participants randomized to the intervention group received weekly visits for 12 weeks by a physical therapist that guided them through an exercise program. The intervention group improved scores in on-the-road driving tests and committed few errors compared with the control group.

Hancock et al. (2002) sought to determine whether spatiotemporal skills, represented by success in a high-level sport, transferred to driving. Using an emergency-braking test, they did not find better performance among young skilled sport practitioners compared with non-practitioners on measures of reaction, movement, or response time.

In a recent study, Matos and Godinho (2009) indicated that a 6-week perceptive-motor program improved the peripheral RT of novice drivers. Measurements were taken in a closed circuit driving test where drivers had to react quickly to peripheral stimuli (LEDs) in both sides of the field of vision while maintaining the car on a well-defined trajectory. They also showed that a group of team-sport players (> than 3 years of practice) had better results than non-sport-players in the peripheral detection task. Thus, it seemed that exercise, and especially one that requires very demanding information processing and accurate event perception, can be positively transferred to the ability of using peripheral vision and divided attention in driving. These results corroborated the previous findings of the same research group showing that basketball players outperformed non-players in a simulated driving task that targeted divided attention (Matos & Godinho, 2005). The transfer of specific skills from sports to driving is probably related to the similarity between the two activities, namely in perceptual and decision-making aspects. The authors stated that the literature already shows better peripheral vision in people engaged in sports compared with those who are not (Cockerill, 1981; Williams & Thirer, 1975) and they hypothesized that the use by the former of a visual "anchor-strategy" consisting in fixating the gaze of vision between two events/objects to capture relevant information (without eye/head movement) (Bard & Fleury, 1976; Kato & Fukuda, 2002) could be positively transferred to driving.

7.Speed of behavior

Traditionally, speed variables have been of great interest to aging researchers. In the present thesis, this variable was one of the outcomes examined when determining the relationship between exercise and driving performance. The main directions of investigation of speed variables have been the (i) increased slowness of behavioral and cognitive processes with advancing adult age as a phenomenon to be explained, and (ii) the reduced speed of processing as a construct to explain age differences in various areas of cognitive functioning (Hartley, 2006). The latter perspective is particularly relevant in the framework of this thesis because it highlights the potential of speed-of-processing training in general cognitive functioning.

One of the most clearly established phenomena of aging is the tendency for slowness of perceptual, motor, and cognitive processes (Birren & Renner, 1977; Der & Deary, 2006; Nicoletti, et al., 2005). Different types of variables have been used to assess the processing speed of an individual, with the particular variables varying according to the research tradition (e.g., decision speed, psychomotor speed, and the time course of event related potentials). Perhaps the most frequently used speed variable is some form of RT (Salthouse, 2000). According to Schmidt and Lee (2005), RT measures are very common in research for two basic reasons: (1) RT measures are components of real-life tasks (e.g., driving), so they often have high face validity, and (2) RT presumably measures the time taken for mental events, such as stimulus processing, decision making, and movement programming.

Despite the various hypotheses considered to explain the age-related slowing of behavior, it is frequently accepted that an increase in RT indicates mainly slowed central processing (e.g., Birren & Renner, 1977). Koga & Morandt's (1923) analyses provided one of the first indication that the slowness in behavior among older persons lay principally within the CNS rather than in the peripheral sensory systems. Magladery (1959) observed that the degenerative changes at the periphery in end organs and nerve pathways cannot possibly account for more than a small fraction of the prolongation in motor response times encountered among older adults. For Salthouse (1985) the controversy is not whether peripheral or central mechanisms are responsible for the slowing with age but rather which central mechanism is the most fundamental.

7.1.Moderators of the influence of age on speed of behavior

A strong interaction between task complexity and age has been established (e.g., Fozard, Vercryssen, Reynolds, Hancock, & Quilter, 1994; McDowd & Craik, 1988). In simple tasks, elderly individuals consistently had slightly slower RTs than their younger counterparts. As tasks became more complex, however, the performance of the elderly worsened to a greater extent than that of young people.

Degraded stimulus (i.e., the decrement of the level of discrimination of the stimulus) seemed to affect the RT performance of older adults more than younger adults (Smulders, Kenemans, Schmidt, & Kok, 1999). Increased age was associated with a variety of health problems, and it is plausible that the health status affected an individual’s processing speed (Salthouse, 2000; Spirduso, et al., 2005). Another potential moderator of the relationship between age and speed is the amount of experience or practice with the tasks. Older experts (e.g., violinists and expert typists) show normal age-related decline in general processing speed but little or no decline in speed measures that are specific to their domain of expertise (Krampe, 2002; Krampe & Erickson, 1996).

Higher levels of education had a protective effect on psychomotor speed (Era, et al., 1986; Houx & Jolles, 1993). Typically, better performances for males than for females have been reported (Adam, et al., 1999; Dane & Erzurumluoglu, 2003; Der & Deary, 2006). However, a recent meta-analysis provided strong evidence that the magnitude of sex differences in simple visual RT has narrowed across time, probably reflecting social changes (e.g., increased participation of women in fast-action sports and driving) (Silverman, 2006). In the driving-related literature, the effects of gender in reaction and movement time are not well established (Morrison, Swope, & Halcomb, 1986; Schweitzer, Apter, Ben-David, Liebermann, & Parush, 1995).

Physical fitness and exercise seem to positively influence the speed of behavior of older adults. Spirduso and Clifford (1978) found that reaction and movement times were directly related to the subjects' level of PA. Old racquetball players were only 7% slower in reacting and 5% slower in moving than young racquetball players. Spirduso (1980) concluded that with physical training, both RT and movement times could be shortened. A recent literature review reported that compared with age-matched but less active controls, veteran tennis players had better RT performance (Marks, 2006). The potential influence of exercise on RT measurements during driving will be an important issue in the experimental chapters of this thesis.

7.2.Theories of age-related slowing

The theories fall into two broad categories: those that explain slowing through general mechanisms or those that attribute the slowing process to specific processes. General slowing theorists support the view that all components of processing decline at approximately the same rate, independently of task complexity and task types (Birren & Fisher, 1995; Birren, Woods, & Williams, 1980). Salthouse (1985) proposed that it is reasonable to expect that other cognitive processes will share some of the causes and perhaps be influenced by the consequences of age-related slowing. This hypothesis led to the conceptualization of a model that held that age differences in the performance of cognitive tasks can be explained by age differences in the speed of processing (e.g., Salthouse, 1993). That is to say, age-related slowing could serve as a construct to explain age-related differences in behaviors presumed to reflect other and various cognitive processes.

Other theorists challenge this view, suggesting that slowing may occur to a great extent in one component of processing versus another and may influence certain variables more than others (e.g., Bashore, Ridderinkhof, & van der Molen, 1997). According to this perspective, slowing does not affect task components in the same manner, but in each case, differential amounts of slowing can be observed. General slowing theorists are criticized because they frequently employed complex psychometric measures that tapped a variety of functions, including not just speed but also attention, working memory, and executive function (Hartley, 2006).

To date, aside from the processing speed hypothesis, other hypotheses have been considered to explain the age-related changes in cognitive performance. Researchers have been searching for a few causes that could have broad effects on many aspects of functioning. According to Hartley (2006), such a search could take place at the level of cognitive constructs (e.g., executive functions), neuroanatomy (e.g., changes in specific brain regions), or neurochemistry (e.g., changes in neurotransmitter systems).

7.3.The speed-accuracy trade-off

One interesting event associated with age is the modification of the speed-accuracy trade-off (Anstey, et al., 2005) which could translate into marked differences in behavior between young and old adults. Chronometric approaches to the study of the effects of age can specifically address this question. In studies using RT as a measure (and where typically high levels of accuracy are needed), models of the speed–accuracy trade-off indicate that there will be large costs in RT for small gains in accuracy at high levels of performance. Thus, relatively small differences between younger and older adults in their response criteria could produce substantial differences in RT (Hartley, 2006).

Perhaps, if one could change this extra-cautiousness behavior of older people (typically they emphasize accuracy rather than speed), their performance differences compared with younger adults could be reduced. A previous study demonstrated that after speed-behavior training in a memory search task, equivalent accuracies were achieved for young and old adults and the response time differences between the groups present at baseline were substantially reduced (Baron & Mattila, 1989). In this experiment, subjects were trained with a deadline procedure in which they were required to constantly increase the speed with which they performed the task. Thus, these data suggest a more substantial improvement in performance related to speed of responding for the old than for the younger adults when exposed to appropriate training.

Exercise programs that regularly include activities dependent on the time to react and execute might be a good strategy to change the conservative relationship between speed and accuracy that is typical in older adults.

8. Mode of exercise and functional status

Mode is often defined as the specific type of activity that a person is performing such as swimming or tennis. If PA is related to cognition in such a way that it either maintains or improves cognitive function, one major question is what type of movement is required to affect this outcome (Spirduso, 2006).

Typically, when prescribing exercise, the type of activity (in combination with intensity and duration) is considered mainly on its repercussion in energy expenditure. Studies regarding the relationship between PA and cognitive functioning are frequently more interested with the physiological demands of exercising than with its demands in cognitive skills. Thus, the enhancement of aerobic fitness (the *cardiovascular fitness hypothesis*) is very often considered as responsible for the enhancement of cognitive functioning that accompanies the practice of PA due to its influence in underlying mechanisms such as cerebral blood flow, BDNF and cerebral structure. The discussions of the biological mechanisms in the literature reviews and meta-analytic studies (Colcombe & Kramer, 2003; Dustman, et al., 1994) reflect this perspective.

As examined previously in the present chapter, it is well-documented that an enriched environment and cognitive training can lead to improved learning and memory as well as structural and morphological changes in the brain (Rampon & Tsien, 2000). Experimental animal studies have shown that exercise associated with planning and execution of complex movements is related to changes in brain structure (Jacini, et al., 2009). As was already mentioned before, some studies demonstrated that exercise characterized by unskilled motor movements increased capillary density without a significant change in synapse number, whereas motor skill learning induced synaptogenesis in higher-order brain regions involved in motor learning with no change in capillary density (Black, et al., 1990; Black, et al., 1987; Kleim, et al., 1997). Thus, the mode of exercise and its specific perceptual and cognitive characteristics/demands are believed to influence the learning and mental performance obtained.

The brain is remarkably plastic in response to experience, and there is already scientific evidence that different types of exercise could have specific repercussions in cognitive functioning. A comparison between a group of internationally competitive judo players and a group of healthy controls showed a significantly higher gray matter tissue density in the brain areas of judo players (Jacini, et al., 2009). Another study (Pereira, et al., 2007) reported that blood volume in the dentate gyrus (the only hippocampal sub-region that supports adult neurogenesis) of adults, assessed by magnetic resonance imaging as an in vivo marker of neurogenesis, increased significantly over a 3-month period of aerobic exercise. Moreover, this increase in dentate gyrus blood volume was significantly correlated with gains in maximal aerobic capacity, and an improvement in short-term memory.

Important findings have been reported in the research about alternative forms of exercise that intend to simultaneously target mind and body (e.g., Tai-Chi and Yoga). Kerr et al. (2008) concluded that the long-term attentional practice's resulting from Tai-Chi had positive effects on a perceptual measure (tactile acuity); the authors suggested that Tai-Chi may elicit long-term plasticity in primary sensory cortical maps. Others have demonstrated improvements in both physical and psychological domains as a consequence of these forms of mind-and-body exercise (Kuramoto, 2006; Kutner, Barnhart, Wolf, McNeely, & Xu, 1997). Considering the evidence that combined cognitive and physical impairments result in a greater increase in disability than either impairment alone (Gill, Williams, Richardson, & Tinetti, 1996), one can consider that interventions that address both domains could provide the greatest opportunity for functional benefit for time spent in exercise (Cress, 2006).

Considering all of these data it seems reasonable that there are certain types of exercise that more effective in promoting physical and mental abilities in older adults. Thus, one of the main objectives of the present thesis is to explore this line of thought by investigating the effects of specific types of exercise/sports on driving ability.

The potential role of physical activity on driving performance and safety among older adults

José Marmeleira, Mário Godinho, Peter Vogelaere

Abstract

The elderly represent the fastest growing driving population. Older drivers have a high crash rate per distance travelled, a high risk of injury or death in traffic accidents, and are commonly found to be 'at fault' in crashes. This reality has focused more interest on issues associated with the fitness to drive and the safety of older drivers. Many older adults depend greatly on their personal vehicle for transportation and suffer a marked loss of quality of life when, as a consequence of no longer being able or permitted to drive, their mobility becomes significantly restricted. The reasons for the deterioration of driving performance that occur during the aging process are multi-factorial and a great deal of research has focused on the identification of those factors. Nevertheless, some studies incorporating training programs have tried, with some success, to improve the driving-related abilities of older drivers. It has been demonstrated that physical activity can promote several skills that are associated with driving performance in older drivers. Few studies, though, have conducted exercise interventions among older drivers intended to enhance their driving-related abilities and promote road safety. In this context, the purpose of this work consists of examining the perceptual, cognitive, health, and physical factors related to fitness to drive in older adults, and identifying possible strategies that can enhance their driving-related abilities. Moreover, potential mechanisms underlying the relationship among PA, driving ability and road safety are discussed.

Key words: Driving, aging, physical activity

European Review of Aging and Physical Activity (2009), 6(1): 29-38.

Introduction

Considering the data regarding road accidents and the demographic evolution, namely the increase in the older population, researchers and public health authorities are showing more interest in issues associated with fitness and safety to drive in older adults. In fact, older adults have become a larger part of the driving population and will continue to do so as “baby boomers” reach retirement age (Lyman, Ferguson, Braver, & Williams, 2002; McGwin & Brown, 1999).

In developed countries the older population has become more dependent on their private cars and it seems very unlikely that other transportation alternatives can fully provide the level of mobility that older adults need (Rosenbloom, 1993, 2001). Driving is essential for older adults to continue their engagement in civic, social, and community life, and to remain involved in the human interactions necessary for health, well-being, and quality of life (Dickerson, et al., 2007; Waller, 1991). Driving cessation has been linked to decreased participation in out-of-home activities and increased depressive symptoms (Fonda, Wallace, & Herzog, 2001; Marottoli, et al., 2000).

The number of crashes per distance travelled is higher in elderly drivers than in all other groups of drivers (Guerrier, Manivannan, & Nair, 1999; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998). Older drivers also have a high risk of injury or death in traffic accidents (Li, Braver, & Chen, 2003; McGwin, Sims, Pulley, & Roseman, 2000) and are commonly found to be ‘at fault’ in crashes (Preusser, et al., 1998). There is strong evidence that older drivers will make up a substantially larger proportion of drivers involved in fatal crashes in the next few decades. This is due to the proportional increase in the older population, the increment of the driving licensure rates, and higher annual distances covered (Lyman, et al., 2002; McGwin & Brown, 1999; Williams, 1989).

Nevertheless, the crash rates for older drivers are lower per capita than for drivers of other ages since they drive shorter distances and are less often licensed to drive (Lyman, et al., 2002; Williams, 1989). Functional declines associated with aging appear to prompt some drivers to voluntarily change their driving habits (Lyman, et al., 2001; Simões, 2003); many older drivers report limiting their driving, especially to avoid complex driving situations such as peak travel times, night-time driving, and adverse weather conditions (Ball, et al., 1998; Keeffe, Jin, Weih, McCarty, & Taylor, 2002). However, because older occupants of vehicles comprise a large proportion of future deaths in motor vehicle crashes, public health efforts to reduce their morbidity and mortality should be pursued (Lyman, et al., 2002).

The most widely recommended road safety strategy for older drivers relates to the restriction of their driving licenses (Tay, 2006). Nevertheless, this type of countermeasure needs to be carefully evaluated due to the negative consequences related to the restriction of elderly mobility, and increased emphasis should be placed on effective methods of protecting older drivers and passengers when they travel in vehicles (Lyman, et al., 2002).

Diverse perceptive, cognitive, and motor factors have been associated with driving difficulties and crash incidence in older adults. In a literature review, Anstey et al. (Anstey, et al., 2005) reported that measures of attention, reaction time, memory, executive function, mental status, visual function, and physical function were associated with driving outcome measures. Health status (e.g., cardiovascular illnesses, diabetes mellitus, state of depression, and dementia) has also been linked with the occurrence of crashes in older drivers (Adler, Rottunda, & Dysken, 2005; McGwin, et al., 2000; Sagberg, 2006).

Aging is associated with a decline in several cognitive skills and brain functions (Bixby, et al., 2007; Spirduso, et al., 2005) which can result in driving difficulties. For example, a decline in information processing speed, loss of efficiency in acquiring new information, cognitive inflexibility, a decline in executive functioning, a reduction in attentional resources, and a reduction in working memory function have been demonstrated (Ball, Vance, Edwards, & Wadley, 2004; Spirduso, et al., 2005).

Interestingly, the practice of physical activities has a positive effect on perceptive, cognitive, and physical abilities as well as on health factors that are considered important for driving performance and safety among older adults. For instance, older people with a good physical fitness level show greater efficiency in information processing (Etnier, et al., 1997; Kramer, et al., 2002), enhancement of attention capacity in dual-task situations (Hawkins, et al., 1992), and better performance on tasks that require visual-spatial processing (Shay & Roth, 1992). The effects of physical activity (PA) on cognitive factors seem to be more accentuated for tasks that request greater attention resources (Chodzko-Zajko & Moore, 1994; Etnier, et al., 1997; van Boxtel, et al., 1997). Furthermore, PA is a key factor for healthful aging (American College of Sports Medicine [ACSM], 1998; World Health Organization [WHO], 1997).

In this context, the purpose of this review is to examine the perceptual, cognitive, health, and physical factors that are related to fitness to drive in older adults and at the same time to identify possible strategies that could enhance their driving-related abilities. Moreover, we intend to identify and analyse the potential mechanisms that could support and promote a relationship between PA, driving ability and road safety.

Visual Attention

Visual attention is a cognitive function involving search, selection, and switching that plays an important role in driving (Richardson & Marottoli, 2003). Changes in visual attention often occur in older adults, leading to marked difficulties in driving (Anstey, et al., 2005; Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Ferreira, Marmeleira, Godinho, & Simões, 2007; Owsley, Ball, Sloane, Roenker, & Bruni, 1991).

Standard clinical measures of visual function tests have demonstrated little sensitivity for identifying risky drivers (Ball & Owsley, 1993; Owsley, et al., 1998). Conversely, a computer-based test - the UFOV® test - supported by the concept of useful field of view (UFOV), was identified as a valid and reliable index of driving performance and safety in older adults (Anstey, et al., 2005). The concept of UFOV was introduced by Sanders (1970), who used the term "functional visual field" to indicate the visual area over which information can be acquired in a brief glance without eye or head movements. The UFOV® test combines the evaluation of visual processing speed, selective and divided visual attention, and evidence has shown that its performance also relies on higher-order cognitive abilities as well as visual sensory function [8].

The possible effects of age on the UFOV have been examined. Ball et al. (1988) found slight differences in visual attention performance between young (22-33 years old) and middle-aged individuals (40-49 years old) but large performance differences between both groups and a sample of elderly individuals (60-75 years old). Other authors have found similar results, suggesting that critical changes in the UFOV occur around 60 years of age (Marmeleira, Godinho, Malarranha, &

Fernandes, 2009; Seiple, Szlyk, Yang, & Holopigian, 1996). However, a recent investigation conducted in a driving simulator reported that middle-aged drivers (46-57 years old) already showed a substantial decrease on the UFOV when their performance was compared with that of younger drivers (21-34 years old) (Rogé, Otmani, Pébayle, & Muzet, 2008). Sekuler et al. (2000) concluded that the UFOV size does not decrease with age but that older people process the received information less efficiently within the UFOV. These changes appear to occur gradually during the normal life-span. Such an interpretation is quite different from that originally suggested by Ball et al. (1988), in which UFOV is constricted in older people.

A study on the relationship between exercise and visual attention have shown that 10 weeks of aerobic exercise (aquatic training) induced a beneficial influence on attention in older adults during dual-task processing (Hawkins, Kramer, Kapaldi, 1992). Roth et al. (2003) concluded that individuals who regularly engaged in PA had significantly better UFOV® scores than less active individuals. Recently, it was reported that elderly individuals who have expertise in orienteering activities have developed attentional skills that outweigh the age-related changes of visual attentional focusing (Pesce, et al., 2007). Marmeleira et al. (2009) showed that an specific exercise program that incorporated open skills and demanding perceptive activities was successful in improving visual attention in a group of older drivers (60 to 81 years old). It has been suggested that participation in exercise programs can induce brain-vascular and neuro-chemical benefits that allow the preservation of attention function in the elderly (Chodzko-Zajko, 1991; Dustman, et al., 1994).

Driver distraction is another critical factor for driving safety and is closely associated with visual attention. It can be defined as the momentary or transient redirection of attention from the task of driving to a thought, object, activity, event or person and represents approximately 24 percent of the human causal factor contribution to all accidents (Caird & Dewar, 2007). It is known that secondary tasks interfere with driving performance, affecting visual search, detection of hazards, and detection of changes in the driving scene (Recarte & Nunes, 2003). Dual-task changes are more frequently observed in older than in younger adults (Bherer, et al., 2005; Chaparro, Wood, & Carberry, 2005).

The research regarding driving and distraction has been focused essentially on the negative effects of using cell phones. Older drivers are more adversely affected by using a cell phone than younger drivers (Chaparro, et al., 2005; Hancock, Lesch, &

Simmons, 2003). On average, reaction time increases by 0.23 sec with cell phone usage, but for older drivers this increase can reach 0.46 sec (Caird & Dewar, 2007).

It is promising that dual-task deficits can be reduced, either by specific cognitive training (Bherer, et al., 2005) or physical exercise (Hawkins, et al., 1992; Marmeleira, et al., 2009).

Executive Function

Executive function consists of a set of higher order cognitive abilities primarily associated with the frontal and prefrontal structures of the brain; it involves skills such as planning, organizing information, inhibiting responses, and orchestrating mental resources (Ball, Wadley, Vance, & Edwards, 2004). This set of skills subserves goal-directed, future-oriented behaviour and does not become automatic over time, requiring constant mediation by a central executor (Colcombe & Kramer, 2003).

Executive function is necessary to plan and coordinate sensorimotor and cognitive responses to complex driving situations and requires adequate working memory resources so that relevant information may be held in mind during the decision making process (Anstey, et al., 2005). Given that the types of crashes in which older adults are involved often occur in complex traffic situations such as intersections (Mayhew, et al., 2006; McGwin & Brown, 1999), it is reasonable to hypothesize that difficulties occur at the level of executive function (i.e., the planning and decision-making part of the driving task) (Anstey, et al., 2005).

Daigneault et al. (2002) found that drivers who had accidents during the previous five years performed poorly on measures of executive functioning. Another study demonstrated that older drivers with mild dementia showed a positive correlation between the results of an on-road driving test and the performance on executive function control and visual attention tests (Whelihan, DiCarlo, & Paul, 2005). Recently, it was reported that executive dysfunction may be an important contributor to pedal errors among older drivers (Freund, Colgrove, Petrakos, & McLeod, 2008) and that poor planning ability is independently associated with driving difficulties (Ferreira, et al., 2007).

In the last several years, relevant investigations have indicated that the frontal neural system (region that mediates executive function) is the primary locus in which aging-related cognitive changes are found and where physical fitness appears to exert its greatest influence (Bixby, et al., 2007; Colcombe & Kramer, 2003; Kramer, et al., 2002). In older adults, it has been suggested that aerobic fitness has a larger impact on tasks that require controlled and effortful processing compared with tasks that are executed using automatic processing (Chodzko-Zajko & Moore, 1994; van Boxtel, et al., 1997). Furthermore, it was found that tasks pertaining to fluid intelligence are more sensitive to physical fitness than those corresponding to crystallized intelligence (Chodzko-Zajko, 1991; Etnier, et al., 1997); executive function and fluid intelligence are related, involving many of the same cognitive processes (Goldstein & Green, 1995).

Colcombe and Kramer (2003), in a meta-analytic review of fitness intervention studies conducted from 1966 through 2001, found a clear and significant effect of aerobic fitness training in the cognitive function of older adults. The fitness effects were more patent in tasks that involved executive control processes. Those authors also found that participation in relatively brief training programs (1-3 months) provided at least as much benefit as moderate training (4-6 months), but not quite as much as long-term training programs (6+ months).

Behavioural Speed

Slowing of motor performance during human aging is well demonstrated in clinical observation (Nicoletti, et al., 2005; Shea, Park, & Braden, 2006; Smith, et al., 1999; Spirduso, et al., 2005). Behavioural speed consists of two major components: reaction time to environmental stimuli and speed of execution (Spirduso, et al., 2005). Evidence suggests that central mechanisms are fundamental in the aging-related slowing of the speed of response and that the sensory and motor factors have only slight effects on that phenomenon (Salthouse, 1985).

The effect of age on reaction time is more pronounced in tasks that have high levels of complexity (Der & Deary, 2006; Luchies, et al., 2002; Stelmach & Nahom, 1992). Reaction time also becomes more variable with age (Der & Deary, 2006; Hultsch, MacDonald, & Dixon, 2002). It has been observed that, although vehicle operations become relatively more automatic with experience, driving is a complex and interactive task involving a variety of skills, requiring the ability to make appropriate and timely decisions (Hancock, et al., 2003; Olson & Dewar, 2007).

Actually, older drivers are frequently involved in crashes that occur in complex traffic situations; for example, older drivers are over-represented in crashes at intersections, in crashes involving failure to yield the right of way, and in crashes occurring while turning and changing lanes (Ball & Owsley, 1993; Mayhew, et al., 2006; McGwin & Brown, 1999).

McKnight and McKnight (1999) found a moderate correlation between reaction time and on-road driving performance, with larger associations found for complex reaction times than for simple ones. Green (2000) suggested that a behavioural-slowing trend occurs with aging, which is reflected in greater brake reaction times. A recent dual-task study demonstrated that performing mental calculations while driving markedly increased the average reaction time of elderly drivers (Makishita & Matsunaga, 2008).

A study of 1425 older drivers (between the ages of 67 and 87 years) showed that age, gender, and cognition are predictive factors for the total brake reaction time (Zhang et al., 2007). The decline in reaction time was associated with low scores in cognitive factors and visual field deficits. The increase in response time was related to having three or more physical complaints related to legs and feet, and poorer vision search. This study concluded that drivers in good physical condition may perform poorly on brake reaction tests if their vision or cognition is compromised.

Research regarding PA has reported better performances on simple and choice reaction tasks among active older adults compared with inactive subjects (ACSM, 1998; Dustman, et al., 1994; Spirduso, 2006). In the driving-related literature, behavioural speed was studied by Hancock et al. (2003) in young athletes on a braking task experiment. Curiously, these authors did not find any advantage of skilled sport practitioners in comparison with non-practitioners in measures of reaction, movement, and response time; they suggested that the advantage of sports participation is not the behavioural speed, but the ability to produce the desirable performance in context. Recently, Matos and Godinho (2007) reported that a specific perceptual-motor training program could enhance the useful field of view and the peripheral reaction time in novice drivers, suggesting that exercise that requires demanding information processing and for which event perception is crucial, could be positively transferred to driving situations. Moreover, Marmeleira et al. (2009) concluded that a type of exercise focusing not only physiological systems but also perceptive and cognitive mechanisms was successful in improving simple reaction in single- and dual-task condition among older drivers.

Health Status

Several health conditions have been associated with the involvement of older drivers in car crashes, namely heart disease, stroke, arthritis, diabetes, a history of myocardial infarction, poor vision, myopia, sleep onset insomnia, frequent tiredness, anxiety or feeling depressed (McGwin, et al., 2000; Sagberg, 2006; Sims, McGwin, Allman, Ball, & Owsley, 2000). The use of nonsteroidal anti-inflammatory drugs, antidepressants, benzodiazepines, angiotensin converting enzyme inhibitors, hypnotic medications, and anticoagulants was also associated with an increased risk of crash involvement (McGwin, et al., 2000; Sagberg, 2006; Sims, et al., 2000).

A large body of laboratory- and population-based studies has documented many health and fitness benefits associated with PA, such as improved physiologic, metabolic, and psychological parameters, as well as a decreased risk for many chronic diseases and premature mortality (e.g., ACSM, 1998; Kesaniemi, et al., 2001; WHO, 1997). Given the link between health and driving performance, the positive influence of physical activity on health could positively influence driving performance in older adults.

The problems associated with dementia are particularly relevant to driving (Adler & Kuskowski, 2003; Klavora & Heslegrave, 2002). Dementia is a syndrome that affects essential cognitive functions like memory, judgment, and psychomotor abilities (Johansson & Lundberg, 1997). Alzheimer's disease is the most common form of dementia (Reger, et al., 2004). Compared to most of the general driving population, drivers with dementia are at an increased risk for unsafe motor-vehicle operation and crashes (Adler, et al., 2005; Fox, Bowden, Bashford, & Smith, 1997; Tuokko, Tallman, Beattie, Cooper, & Weir, 1995). Friedland et al. (1988) reported that 77% of patients with dementia of the Alzheimer's type showed deterioration in driving performance and that 63% of those patients stopped driving; however, only 42% of the patients with dementia who stopped driving did so before a crash occurred. Many individuals with dementia continue to drive even after the onset of symptoms (Adler & Kuskowski, 2003).

The risk of dementia, cognitive impairment, cognitive decline, and Alzheimer's disease is lower among persons engaging in high levels of PA, compared with those performing low levels of PA (Rockwood & Middleton, 2008). A study conducted in the United States with 3375 men and women, aged 65 years or older, showed that participants in the highest quartile of physical energy expenditure had a relative risk of dementia of 0.85 compared with those in the lowest quartile (Podewils, et al., 2005).

Since driving is an intense visual task, it has long been thought that visual impairment should be associated with crash risk (Rubin, et al., 2007). Frequently, satisfactory performance on a vision test (often only a visual acuity test) is required to obtain a driver's licence (Keeffe, et al., 2002). Most aspects of visual function decline after the age of 50 years (Johnson & Choy, 1987). Studies have found that drivers with changes in visual acuity, glare sensitivity, binocular visual field, or contrast sensitivity have a greater crash risk (Gresset & Meyer, 1994; Hofstetter, 1976; Owsley, Stalvey, Wells, Sloane, & McGwin, 2001; Rubin, et al., 2007). However, most studies have shown weak or no association between crash risk and visual function either in the general driving population or among older drivers (Anstey, et al., 2005; Charman, 1997; Keeffe, et al., 2002; Owsley, et al., 1998). Overall, the scientific literature suggests that visual tests used in isolation are not strong predictors of crash involvement because they do not tap into the visual and cognitive complexity of the driving task (Anstey, et al., 2005; Ball & Owsley, 1993; Owsley, et al., 1998).

Physical Functioning

A history of falls and poor mobility have been found to be associated with driving difficulties or crash involvement in older drivers (Ball, et al., 2006; Lyman, et al., 2001; Marottoli, Cooney, Wagner, Doucette, & Tinetti, 1994; Sims, McGwin, Pulley, & Roseman, 2001; Sims, Owsley, Allman, Ball, & Smoot, 1998). Poor neck rotation was also found to be related to an increased risk of crashing (Marottoli, et al., 1998). Moratolli and Drickamer (1993) considered that the key elements of motor ability for older drivers include strength, range-of-motion of the extremities, trunk and neck mobility, and proprioception. However, they noted that limited information is available on the specific level of motor ability necessary for driving.

Previous investigations have explored the potential link between physical training and driving-related abilities. Morattoli et al. (2007) demonstrated the possibility of maintaining or enhancing driving performance among physically impaired older drivers (>70 years of age) using a safe, well-tolerated multicomponent physical conditioning program. The intervention protocol targeted axial/extremity range of motion (e.g,, cervical and trunk rotation; ankle dorsiflexion and plantarflexion), upper extremity coordination/dexterity, hand strength, gait, and foot abnormalities.

A randomized control trial reported that an 8-week range-of-motion exercise training program successfully improved older drivers' shoulder flexibility and trunk rotation, as well as their scores on the variable “observing” (percentage of appropriate responses in observing to the rear, side, and rear quarter, involving use of mirrors, turning the head, and looking over the shoulder)(Ostrow, Shaffron, & McPherson, 1992). Tuokko et al. (2007) found that older adults with lower PA levels had evident driving difficulties involving the spine and lower body. They suggested that PA focused on the improvement of spinal flexibility could enhance specific aspects of driving performance, such as turning to check for traffic or operating a seat belt. Those authors considered it to be encouraging that the most frequently reported symptoms were located in areas highly amenable to modification and pointed out that most of the older drivers expressed a willingness to engage in exercise programs if an association between physical fitness and driving could be demonstrated.

Speed perception

Speed perception has been identified as an important ability for safe driving (Hesketh & Godley, 2002; Marmeleira, Ferreira, Godinho, & Fernandes, 2007; Raghuram & Lakshminarayanan, 2006). This concept is frequently known as Time-to-Contact (TTC) (Manser & Hancock, 1996). Despite some methodological differences, studies about driving concerning TTC are linked with the visual perception of approaching vehicles. One of the main differences in methodology is related to the fact that the observer is stationary or in-motion. TTC involves primarily the local transformation of optical information through changes in the size of the image on the retina (Hesketh & Godley, 2002; Manser & Hancock, 1996).

A high proportion of accidents involving older drivers occur at intersections when entering the traffic or crossing a main road (Mayhew, et al., 2006). In those situations, it is very important to correctly perceive speed, distance, and “time away” of the approaching vehicle (Hesketh & Godley, 2002; McGwin & Brown, 1999). Previous findings have indicated that older drivers underestimate the TTC of other vehicles to a greater degree than younger drivers (Leung & Starmer, 2005; Schiff, Oldak, & Shah, 1992).

It is a common idea that less accuracy or more variability in the TTC perception of older drivers, combined with factors such as longer road crossing times, could explain their tendency to be more conservative than young drivers when deciding to enter traffic, accepting larger gaps, and by this means, trying to reduce the probability of a traffic accident (Keskinen, Ota, & Katila, 1998; Skaar, Rizzo, & Stierman, 2003). Relative underestimation of TTC might reflect some loss of perception capability. On the other hand, it could be beneficial for promoting a more preventive behaviour, such as encouraging drivers to choose larger gaps between successive oncoming vehicles (Hesketh & Godley, 2002).

Female drivers tend to exhibit larger TTC underestimations than male drivers (Leung & Starmer, 2005; Schiff, et al., 1992). Women often evaluate their driving capabilities more negatively than men, reporting more driving difficulties (Ferreira, et al., 2007), which could lead to more cautious behaviour. A review of this issue concluded that, after controlling for driving exposure, women were less likely to be involved in vehicle crashes than men, and gender differences were greater among young and inexperienced drivers (Elander, West, & French, 1993).

In the driving-related literature, we have only found one study (Marmeleira, Godinho, & Fernandes, 2009) that examined the effects of exercise on speed perception in older drivers. After 12 weeks of exercise there was no evidence of any positive effect on speed perception.

Training programs for older drivers

A great deal of research has focused on elderly drivers' crash-involvement patterns, but not on the development and evaluation of methods allowing the enhancement of their driving-related abilities (Kua, Korner-Bitensky, Desrosiers, Man-Son-Hing, & Marshall, 2007). However, some scientific research has examined the effectiveness of retraining programs for older drivers using interventions in areas such as education, visual attention, or physical functioning. In-class and on-road education programs may help older drivers to improve their knowledge of safe driving practices and actual driving performances (Bedard, et al., 2008; Marottoli, Ness, et al., 2007). However, not all education interventions have been found to improve driving performance in older drivers (Bedard, Isherwood, Moore, Gibbons, & Lindstrom, 2004), and there is no evidence that post-license educational programs are effective in preventing road traffic crashes (Bedard, et al., 2008; Ker, et al., 2005).

Other methods have been used to enhance driving-related abilities in older adults. It has been reported that visual attention retraining programs using the UFOV® software resulted in fewer dangerous manoeuvres during an open-road driving evaluation (Ball, 1997; Roenker, et al., 2003) and that simulator-training was capable of enhancing driving performance in older adults (Akinwuntan, et al., 2005; Roenker, et al., 2003). As already described, some studies have also demonstrated that programs focused on physical mobility retraining could enhance driving skills (Marottoli, Ness, et al., 2007; Ostrow, et al., 1992).

Some interventions for older drivers have focused only on high-risk groups. Owsley et al. (2004) reported that an educational program promoting safe-driving strategies among visually impaired older drivers did not enhance driving safety. Kooijman et al. (2004), in a study among drivers with visual field defects, reported that a compensatory viewing training (laboratory and mobility training, including driving instruction) improved the driving performance in an on-road test.

Interestingly, research among older drivers has not consistently explored the possible benefits of multi-faceted intervention programs that integrates educational, motor, sensory, and cognitive components; all of those factors have individually been shown to be reasonably effective in improving driving behaviour (Kua, et al., 2007). It is promising that in a recent experimental study, a specific exercise program planned to stress perceptive, cognitive, and physical abilities was successful in improving several abilities (behavioural speed, visual attention and psychomotor performance) considered critical for driving performance and safety among older adults (Marmeleira, et al., 2009). Given that the task of driving involves a complex interplay of factors, more specific intervention programs capable of targeting several important domains are needed.

Summary

The elderly represent the fastest growing driving population, and despite their lower crash rates per capita compared with drivers of other ages, they are believed to represent a high risk to road safety given their high crash rate per distance travelled.

Many older adults depend greatly on their personal automobile for transportation. They suffer a marked loss of quality of life when their mobility becomes significantly restricted, as a result of being no longer able or permitted to drive.

The reasons for the deterioration in driving performance occur along the aging process and are multi-factorial. A great deal of safety research on older drivers has focused on the identification of these factors. Some training programs directed to factors like visual attention, physical mobility, and driving education have improved the driving performance of older drivers.

It has been demonstrated that PA is capable of enhancing several perceptive, cognitive, physical, and health factors associated with driving performance in older drivers. However, few studies have conducted exercise interventions among older drivers that were intended to enhance their driving-related abilities and promote road safety.

Future research should explore the potential role of PA in preventing the deterioration or enhancing the driving-related abilities of older adults.

REFERENCES

Aartsen, M. J., Smits, C. H., van Tilburg, T., Knipscheer, K. C., & Deeg, D. J. (2002). Activity in older adults: cause or consequence of cognitive functioning? A longitudinal study on everyday activities and cognitive performance in older adults. *J Gerontol B Psychol Sci Soc Sci, 57*(2), P153-162.

Adam, J. J., Paas, F. G., Buekers, M. J., Wuyts, I. J., Spijkers, W. A., & Wallmeyer, P. (1999). Gender differences in choice reaction time: evidence for differential strategies. *Ergonomics, 42*(2), 327-335.

Adler, G., & Kuskowski, M. (2003). Driving cessation in older men with dementia. *Alzheimer Dis Assoc Disord, 17*(2), 68-71.

Adler, G., Rottunda, S., & Dysken, M. (2005). The older driver with dementia: an updated literature review. *J Safety Res, 36*(4), 399-407.

Ajmani, R. S., Metter, E. J., Jaykumar, R., Ingram, D. K., Spangler, E. L., Abugo, O. O., et al. (2000). Hemodynamic changes during aging associated with cerebral blood flow and impaired cognitive function. *Neurobiol Aging, 21*(2), 257-269.

Akinwuntan, A. E., De Weerdt, W., Feys, H., Pauwels, J., Baten, G., Arno, P., et al. (2005). Effect of simulator training on driving after stroke: a randomized controlled trial. *Neurology, 65*(6), 843-850.

Altman, J. (1962). Are new neurons formed in the brains of adult mammals? *Science, 135*, 1127-1128.

American College of Sports Medicine (1998). Position Stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc, 30*(6), 992-1008.

Ando, S., Kida, N., & Oda, S. (2001). Central and peripheral visual reaction time of soccer players and nonathletes. *Percept Mot Skills, 92*(3 Pt 1), 786-794.

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clin Psychol Rev, 25*(1), 45-65.

Ball, K. (1997). Enhancing mobility in the elderly: attentional interventions for driving. In S. M. C. Dollinger & L. F. DiLalla (Eds.), *Assessment and intervention issues across the life span*. Mahwah, NJ: Lawrence. Erlbaum Associates.

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., et al. (2002). Effects of cognitive training interventions with older adults: a randomized controlled trial. *JAMA, 288*(18), 2271-2281.

Ball, K., Edwards, J. D., & Ross, L. A. (2007). The impact of speed of processing training on cognitive and everyday functions. *J Gerontol B Psychol Sci Soc Sci, 62 Spec No 1*, 19-31.

Ball, K., & Owsley, C. (1993). The useful field of view test: a new technique for evaluating age-related declines in visual function. *J Am Optom Assoc, 64*(1), 71-79.

Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Invest Ophthalmol Vis Sci, 34*(11), 3110-3123.

Ball, K., Owsley, C., Stalvey, B., Roenker, D. L., Sloane, M. E., & Graves, M. (1998). Driving avoidance and functional impairment in older drivers. *Accid Anal Prev, 30*(3), 313-322.

Ball, K., Vance, D., Edwards, J., & Wadley, V. (2004). Aging and the brain. In M. Rizzo & P. Eslinger (Eds.), *Principles and Practices of Behavioral Neurology and Neuropsychology* (pp. 795-809). Philadelphia: W.B. Saunders, Elsevier.

Ball, K., Wadley, V., Vance, D., & Edwards, J. (2004). Cognitive skills: training, maintenance, and daily usage. In C. Speilberg (Ed.), *Encylopedia of Applied Psychology* (pp. 387-392): Elsevier Science.

Ball, K. K., Beard, B. L., Roenker, D. L., Miller, R. L., & Griggs, D. S. (1988). Age and visual search: expanding the useful field of view. *J Opt Soc Am A, 5*(12), 2210-2219.

Ball, K. K., Roenker, D. L., Wadley, V. G., Edwards, J. D., Roth, D. L., McGwin, G., Jr., et al. (2006). Can high-risk older drivers be identified through performance-based measures in a Department of Motor Vehicles setting? *J Am Geriatr Soc, 54*(1), 77-84.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice Hall.

Bandura, A. (1989). Regulation of cognitive processes through perceived self-efficacy. *Developmental psychology, 25*(5), 729-735.

Bard, C., & Fleury, M. (1976). Analysis of visual search activity during sport problem situations. *J Hum Movement Stud, 3*, 214-222.

Baron, A., & Mattila, W. R. (1989). Response slowing of older adults: effects of time-limit contingencies on single- and dual-task performances. *Psychol Aging, 4*(1), 66-72.

Bashore, T. R., & Goddard, P. H. (1993). Preservative and restoring effects of aerobic fitness in the age-related slowing of mental processing speed. In J. Cerella, J. Rybash, W. Hoyer & M. L. Commons (Eds.), *Adult information processing: Limits on loss*. San Diego, CA: Academic.

Bashore, T. R., Ridderinkhof, K. R., & van der Molen, M. W. (1997). The decline of cognition processin speed in old age. *Curr Dir Psychol Sci, 6*(6), 163-169.

Baylor, A. M., & Spirduso, W. W. (1988). Systematic aerobic exercise and components of reaction time in older women. *J Gerontol, 43*(5), P121-126.

Bedard, M., Isherwood, I., Moore, E., Gibbons, C., & Lindstrom, W. (2004). Evaluation of a re-training program for older drivers. *Can J Public Health, 95*(4), 295-298.

Bedard, M., Porter, M. M., Marshall, S., Isherwood, I., Riendeau, J., Weaver, B., et al. (2008). The combination of two training approaches to improve older adults' driving safety. *Traffic Inj Prev, 9*(1), 70-76.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: are there age-related differences in plasticity of attentional control? *Psychol Aging, 20*(4), 695-709.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: further evidence for cognitive plasticity in attentional control in late adulthood. *Exp Aging Res, 34*(3), 188-219.

Bielak, A. A. (2010). How Can We Not 'Lose It' if We Still Don't Understand How to 'Use It'? Unanswered Questions about the Influence of Activity Participation on Cognitive Performance in Older Age - A Mini-Review. *Gerontology, 56*(5), 507-519.

Bielak, A. A., Hughes, T. F., Small, B. J., & Dixon, R. A. (2007). It's never too late to engage in lifestyle activities: significant concurrent but not change relationships between lifestyle activities and cognitive speed. *J Gerontol B Psychol Sci Soc Sci, 62*(6), P331-339.

Biernaskie, J., & Corbett, D. (2001). Enriched rehabilitative training promotes improved forelimb motor function and enhanced dendritic growth after focal ischemic injury. *J Neurosci, 21*(14), 5272-5280.

Birren, J. E., & Fisher, L. M. (1995). Aging and speed of behavior: possible consequences for psychological functioning. *Annu Rev Psychol, 46*, 329-353.

Birren, J. E., & Renner, V. J. (1977). Research on the psychology of aging: Principles and experimentation. In J. E. Birren & K. W. E. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 3-38). New York: Van Nostrand Reinhold.

Birren, J. E., Woods, A. M., & Williams, M. V. (1980). Behavioral slowing with age: causes, organization, and consequences. In L. W. Poon (Ed.), *Aging in the 1980s: Psychological Issues* (pp. 293-308). Washington, DC: Am. Psychol. Assoc.

Bixby, W. R., Spalding, T. W., Haufler, A. J., Deeny, S. P., Mahlow, P. T., Zimmerman, J. B., et al. (2007). The unique relation of physical activity to executive function in older men and women. *Med Sci Sports Exerc, 39*(8), 1408-1416.

Black, J. E., Isaacs, K. R., Anderson, B. J., Alcantara, A. A., & Greenough, W. T. (1990). Learning causes synaptogenesis, whereas motor activity causes angiogenesis, in cerebellar cortex of adult rats. *Proc Natl Acad Sci U S A, 87*(14), 5568-5572.

Black, J. E., Sirevaag, A. M., & Greenough, W. T. (1987). Complex experience promotes capillary formation in young rat visual cortex. *Neurosci Lett, 83*(3), 351-355.

Blumenthal, J. A., Emery, C. F., Madden, D. J., Schniebolk, S., Walsh-Riddle, M., George, L. K., et al. (1991). Long-term effects of exercise on psychological functioning in older men and women. *J Gerontol, 46*(6), P352-361.

Bosma, H., Van Boxtel, M., Ponds, R., Houx, P., & Jolles, J. (2003). Education and age-related cognitive decline: The contribution of mental workload. *Educ Gerontol, 29*(2), 165-173.

Brown, B. S., Payne, T., Kim, C., Moore, G., Krebs, P., & Martin, W. (1979). Chronic response of rat brain norepinephrine and serotonin levels to endurance training. *J Appl Physiol, 46*(1), 19-23.

Caird, J., & Dewar, R. (2007). Driver distracion. In R. Dewar & P. Olson (Eds.), *Human factors in traffic safety.* (pp. 195-222). Tucson: Laywers & Judges publishing Co., Inc.

Carro, E., Nunez, A., Busiguina, S., & Torres-Aleman, I. (2000). Circulating insulin-like growth factor I mediates effects of exercise on the brain. *J Neurosci, 20*(8), 2926-2933.

Carro, E., Trejo, J. L., Busiguina, S., & Torres-Aleman, I. (2001). Circulating insulin-like growth factor I mediates the protective effects of physical exercise against brain insults of different etiology and anatomy. *J Neurosci, 21*(15), 5678-5684.

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep, 100*(2), 126-131.

Cassavaugh, N. D., & Kramer, A. F. (2009). Transfer of computer-based training to simulated driving in older adults. *Appl Ergon, 40*(5), 943-952.

Castiello, U., & Umiltá, C. (1992). Orienting of attention in volleyball players. *International Journal of Sport Psychology, 23*(4), 301-310.

Cavanaugh, J. C. (1990). The importance of awareness in memory aging. In L. W. Poon, D. C. Rubin & B. A. Wilson (Eds.), *Everyday cognition in adulthood and late life* (pp. 416-436). New York: Cambridge University Press.

Chang, Y., & Etnier, J. (2009). Effects of an acute bout of localized resistance exercise on cognitive performance in middle-aged adults: A randomized controlled trial study. *Psychol J Sport Exerc, 10*(1), 19-24.

Chaparro, A., Wood, J. M., & Carberry, T. (2005). Effects of age and auditory and visual dual tasks on closed-road driving performance. *Optom Vis Sci, 82*(8), 747-754.

Charman, W. N. (1997). Vision and driving--a literature review and commentary. *Ophthalmic Physiol Opt, 17*(5), 371-391.

Chodzko-Zajko, W. J. (1991). Physical fitness, cognitive performance, and aging. *Med Sci Sports Exerc, 23*(7), 868-872.

Chodzko-Zajko, W. J., & Moore, K. A. (1994). Physical fitness and cognitive functioning in aging. *Exerc Sport Sci Rev, 22*, 195-220.

Chodzko-Zajko, W. J., Proctor, D. N., Fiatarone Singh, M. A., Minson, C. T., Nigg, C. R., Salem, G. J., et al. (2009). American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc, 41*(7), 1510-1530.

Christensen, H., Korten, A., Jorm, A. F., Henderson, A. S., Scott, R., & Mackinnon, A. J. (1996). Activity levels and cognitive functioning in an elderly community sample. *Age Ageing, 25*(1), 72-80.

Churchill, J. D., Galvez, R., Colcombe, S., Swain, R. A., Kramer, A. F., & Greenough, W. T. (2002). Exercise, experience and the aging brain. *Neurobiol Aging, 23*(5), 941-955.

Cockerill, I. (1981). Peripheral vision and hockey. In I. Cockerill & W. MacGillivary (Eds.), *Vision and sport* (pp. 54-63). London: S. Thornes Publishers.

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci, 14*(2), 125-130.

Colcombe, S. J., Erickson, K. I., Raz, N., Webb, A. G., Cohen, N. J., McAuley, E., et al. (2003). Aerobic fitness reduces brain tissue loss in aging humans. *J Gerontol A Biol Sci Med Sci, 58*(2), 176-180.

Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R., McAuley, E., et al. (2006). Aerobic exercise training increases brain volume in aging humans. *J Gerontol A Biol Sci Med Sci, 61*(11), 1166-1170.

Cotman, C. W., & Berchtold, N. C. (2002). Exercise: a behavioral intervention to enhance brain health and plasticity. *Trends Neurosci, 25*(6), 295-301.

Cress, M. E. (2006). Assessing physical performance in older adults. In L. W. Poon, W. J. Chodzko-Zajko & P. D. Tomporowski (Eds.), *Active living, cognitive functioning, and aging* (pp. 113-132). Champaign: Human Kinetics.

Daigneault, G., Joly, P., & Frigon, J. Y. (2002). Executive functions in the evaluation of accident risk of older drivers. *J Clin Exp Neuropsychol, 24*(2), 221-238.

Dane, S., & Erzurumluoglu, A. (2003). Sex and handedness differences in eye-hand visual reaction times in handball players. *Int J Neurosci, 113*(7), 923-929.

Der, G., & Deary, I. J. (2006). Age and sex differences in reaction time in adulthood: results from the United Kingdom Health and Lifestyle Survey. *Psychol Aging, 21*(1), 62-73.

Dickerson, A. E., Molnar, L. J., Eby, D. W., Adler, G., Bedard, M., Berg-Weger, M., et al. (2007). Transportation and aging: a research agenda for advancing safe mobility. *Gerontologist, 47*(5), 578-590.

Dienstbier, R. A. (1989). Arousal and physiological toughness: implications for mental and physical health. *Psychol Rev, 96*(1), 84-100.

Dienstbier, R. A. (1991). Behavioral correlates of sympathoadrenal reactivity: the toughness model. *Med Sci Sports Exerc, 23*(7), 846-852.

Dratcu, L. (2009). [The future of depression: a complex neuroendocrine, inflammatory and neurodegenerative systemic illness.]. *Vertex, 20*(87), 329-341.

Dustman, R., Emmerson, R., & Schearer, D. (1994). Physical Activity, age, and cognitive neuropsychological function. *J Aging Phys Act, 2*, 143-181.

Dustman, R., & White, A. (2006). Effects of exercise on cognition in older adults: A reexamination of proposed mechanisms. In L. W. Poon, W. Chodzko-Zajko & P. D. Tomporowski (Eds.), *Active living, Cognitive Functioning and Aging* (pp. 51-74). Champaign: Human Kinetics.

Dustman, R. E., Emmerson, R. Y., Ruhling, R. O., Shearer, D. E., Steinhaus, L. A., Johnson, S. C., et al. (1990). Age and fitness effects on EEG, ERPs, visual sensitivity, and cognition. *Neurobiol Aging, 11*(3), 193-200.

Dustman, R. E., Ruhling, R. O., Russell, E. M., Shearer, D. E., Bonekat, H. W., Shigeoka, J. W., et al. (1984). Aerobic exercise training and improved neuropsychological function of older individuals. *Neurobiol Aging, 5*(1), 35-42.

Edwards, J. D., Delahunt, P. B., & Mahncke, H. W. (2009). Cognitive speed of processing training delays driving cessation. *J Gerontol A Biol Sci Med Sci, 64*(12), 1262-1267.

Edwards, J. D., Myers, C., Ross, L. A., Roenker, D. L., Cissell, G. M., McLaughlin, A. M., et al. (2009). The longitudinal impact of cognitive speed of processing training on driving mobility. *Gerontologist, 49*(4), 485-494.

Edwards, J. D., Wadley, V. G., Myers, R. S., Roenker, D. L., Cissell, G. M., & Ball, K. K. (2002). Transfer of a speed of processing intervention to near and far cognitive functions. *Gerontology, 48*(5), 329-340.

Edwards, J. D., Wadley, V. G., Vance, D. E., Wood, K., Roenker, D. L., & Ball, K. K. (2005). The impact of speed of processing training on cognitive and everyday performance. *Aging Ment Health, 9*(3), 262-271.

Elander, J., West, R., & French, D. (1993). Behavioral correlates of individual differences in road-traffic crash risk: an examination method and findings. *Psychol Bull, 113*(2), 279-294.

Emery, C. F., & Gatz, M. (1990). Psychological and cognitive effects of an exercise program for community-residing older adults. *Gerontologist, 30*(2), 184-188.

Endres, M., Gertz, K., Lindauer, U., Katchanov, J., Schultze, J., Schrock, H., et al. (2003). Mechanisms of stroke protection by physical activity. *Ann Neurol, 54*(5), 582-590.

Era, P., Jokela, J., & Heikkinen, E. (1986). Reaction and movement times in men of different ages: a population study. *Percept Mot Skills, 63*(1), 111-130.

Eriksson, P. S., Perfilieva, E., Bjork-Eriksson, T., Alborn, A. M., Nordborg, C., Peterson, D. A., et al. (1998). Neurogenesis in the adult human hippocampus. *Nat Med, 4*(11), 1313-1317.

Etnier, J. (2008). Interrelationships of exercise, mediator variables, and cognition. In W. W. Spirduso, L. W. Poon & Chodzko-Zajko (Eds.), *Exercise and its mediating effects on cognition* (pp. 13-32). Champaign, IL: Human Kinetics.

Etnier, J. L. (2009). Physical activity programming to promote cognitive function: are we ready for prescription? In W. J. Chodzko-Zajko, A. F. Kramer & L. W. Poon (Eds.), *Enhance cognitive functioning and brain plasticity* (pp. 159-175). Champaign: Human Kinetics.

Etnier, J. L., Nowell, P. M., Landers, D. M., & Sibley, B. A. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Res Rev, 52*(1), 119-130.

Etnier, J. R., Salazar, W., Landers, D. M., Petruzzello, S. J., Han, M., & Novell, P. (1997). The influence of physical fitness and exercise upon cognitive functioning: a meta analysis. *J. Sport Exerc. Psychol., 19*, 249-277.

European Comission (2008). *What can the European Union do to protect dignity in old age and prevent elder abuse?* Brussels: Employment, Social Affairs and Equal Opportunities DG

Ferreira, I., Marmeleira, J., Godinho, M., & Simões, M. (2007). *Cognitive factors and gender related to self-reported difficulties in older drivers.* Paper presented at the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Stevenson, Washington.

Fonda, S. J., Wallace, R. B., & Herzog, A. R. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. *J Gerontol B Psychol Sci Soc Sci, 56*(6), S343-351.

Fox, G. K., Bowden, S. C., Bashford, G. M., & Smith, D. S. (1997). Alzheimer's disease and driving: prediction and assessment of driving performance. *J Am Geriatr Soc, 45*(8), 949-953.

Fozard, J. L., Vercryssen, M., Reynolds, S. L., Hancock, P. A., & Quilter, R. E. (1994). Age differences and changes in reaction time: The Baltimore Longitudinal Study of Aging. *Journal of Gerontology, 49*, 179-189.

Freund, B., Colgrove, L. A., Petrakos, D., & McLeod, R. (2008). In my car the brake is on the right: pedal errors among older drivers. *Accid Anal Prev, 40*(1), 403-409.

Friedland, R. P. (1990). Brain imaging and cerebral metabolism. In F. Boller & J. Grafman (Eds.), *Handbook of neropsychology* (pp. 197-211). Amsterdam: Elsevier Science.

Friedland, R. P., Koss, E., Kumar, A., Gaine, S., Metzler, D., Haxby, J. V., et al. (1988). Motor vehicle crashes in dementia of the Alzheimer type. *Ann Neurol, 24*(6), 782-786.

Gellatly, I., & Meyer, J. (1992). The effects of goal difficulty on physiological arousal, cognition, and task performance. *J Appl Psychol, 77*, 694-694.

Ghisletta, P., Bickel, J. F., & Lovden, M. (2006). Does activity engagement protect against cognitive decline in old age? Methodological and analytical considerations. *J Gerontol B Psychol Sci Soc Sci, 61*(5), P253-261.

Gill, T. M., Williams, C. S., Richardson, E. D., & Tinetti, M. E. (1996). Impairments in physical performance and cognitive status as predisposing factors for functional dependence among nondisabled older persons. *J Gerontol A Biol Sci Med Sci, 51*(6), M283-288.

Goldstein, F. C., & Green, R. C. (1995). Assessment of problem solving and executive functions. In R. L. Mapou & J. Spector (Eds.), *Clinical neuropsychological assessment: A cognitive approach* (pp. 49-81). New York: Plenum.

Gould, E., Beylin, A., Tanapat, P., Reeves, A., & Shors, T. J. (1999). Learning enhances adult neurogenesis in the hippocampal formation. *Nat Neurosci, 2*(3), 260-265.

Gould, E., Reeves, A. J., Graziano, M. S., & Gross, C. G. (1999). Neurogenesis in the neocortex of adult primates. *Science, 286*(5439), 548-552.

Gould, E., Vail, N., Wagers, M., & Gross, C. G. (2001). Adult-generated hippocampal and neocortical neurons in macaques have a transient existence. *Proc Natl Acad Sci U S A, 98*(19), 10910-10917.

Gould, E., Woolley, C. S., & McEwen, B. S. (1990). Short-term glucocorticoid manipulations affect neuronal morphology and survival in the adult dentate gyrus. *Neuroscience, 37*(2), 367-375.

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*(6939), 534-537.

Green, C. S., & Bavelier, D. (2008). Exercising your brain: a review of human brain plasticity and training-induced learning. *Psychol Aging, 23*(4), 692-701.

Green, M. (2000). How long does it take to stop? Methodological analysis of driver perception-brake times. *Transport Hum Factors 2*(3), 195-216.

Gresset, J. A., & Meyer, F. M. (1994). Risk of accidents among elderly car drivers with visual acuity equal to 6/12 or 6/15 and lack of binocular vision. *Ophthalmic Physiol Opt, 14*(1), 33-37.

Guerrier, J. H., Manivannan, P., & Nair, S. N. (1999). The role of working memory, field dependence, visual search, and reaction time in the left turn performance of older female drivers. *Appl Ergon, 30*(2), 109-119.

Hancock, P. A., Kane, M. J., Scallen, S., & Albinson, C. B. (2002). Effects of gender and athletic participation on driving capability. *Int J Occup Saf Ergon, 8*(2), 281-292.

Hancock, P. A., Lesch, M., & Simmons, L. (2003). The distraction effects of phone use during a crucial driving maneuver. *Accid Anal Prev, 35*(4), 501-514.

Harle, S., & Vickers, J. (2001). Training quiet eye improves accuracy in the basketball free throw. *Sport Psychologist, 15*(3), 289-305.

Hartley, A. (2006). Changing Role of the Speed of Processing Construct in the Cognitive Psychology of Human Aging. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of The Psychology of Aging* (Sixth ed., pp. 183-207). Burlington, MA: Elsevier Academic Press.

Hattori, S., Naoi, M., & Nishino, H. (1994). Striatal dopamine turnover during treadmill running in the rat: relation to the speed of running. *Brain research bulletin, 35*(1), 41-49.

Hawkins, H. L., Kramer, A. F., & Capaldi, D. (1992). Aging, exercise, and attention. *Psychol Aging, 7*(4), 643-653.

Helsen, W., & Starkes, J. (1999). A multidimensional approach to skilled perception and performance in sport. *Appl Cogn Psychol, 13*(1), 1-27.

Hesketh, B., & Godley, S. T. (2002). A comparison of time estimations in driving with target-only in motion, self-only in motion, and self-and-target in motion. *Ecol Psychol, 14*(3), 111-125.

Hofstetter, H. W. (1976). Visual acuity and highway accidents. *J Am Optom Assoc, 47*(7), 887-893.

Houx, P. J., & Jolles, J. (1993). Age-related decline of psychomotor speed: effects of age, brain health, sex, and education. *Percept Mot Skills, 76*(1), 195-211.

Hultsch, D. F., Hammer, M., & Small, B. J. (1993). Age differences in cognitive performance in later life: relationships to self-reported health and activity life style. *J Gerontol, 48*(1), P1-11.

Hultsch, D. F., Hertzog, C., Small, B. J., & Dixon, R. A. (1999). Use it or lose it: engaged lifestyle as a buffer of cognitive decline in aging? *Psychol Aging, 14*(2), 245-263.

Hultsch, D. F., MacDonald, S. W., & Dixon, R. A. (2002). Variability in reaction time performance of younger and older adults. *J Gerontol B Psychol Sci Soc Sci, 57*(2), P101-115.

Izquierdo-Porrera, A. M., & Waldstein, S. R. (2002). Cardiovascular risk factors and cognitive function in African Americans. *J Gerontol B Psychol Sci Soc Sci, 57*(4), P377-380.

Jacini, W. F., Cannonieri, G. C., Fernandes, P. T., Bonilha, L., Cendes, F., & Li, L. M. (2009). Can exercise shape your brain? Cortical differences associated with judo practice. *J Sci Med Sport, 12*(6), 688-690.

Jacobs, B., Schall, M., & Scheibel, A. (1993). A quantitative dendritic analysis of Wernicke's area in humans. II. Gender, hemispheric, and environmental factors. *J Comp Neurol, 327*(1), 97-111.

Johansson, K., & Lundberg, C. (1997). The 1994 International Consensus Conference on Dementia and Driving: a brief report. Swedish National Road Administration. *Alzheimer Dis Assoc Disord, 11 Suppl 1*, 62-69.

Johnson, M. A., & Choy, D. (1987). On the definition of age-related norms for visual function testing. *Appl Opt, 26*, 1449-1454.

Judd, C. (1908). The relation of special training to general intelligence. *Educational Review, 36*(28-42).

Kamijo, K., Hayashi, Y., Sakai, T., Yahiro, T., Tanaka, K., & Nishihira, Y. (2009). Acute effects of aerobic exercise on cognitive function in older adults. *J Gerontol B Psychol Sci Soc Sci, 64*(3), 356-363.

Kato, T., & Fukuda, T. (2002). Visual search strategies of baseball batters: Eye movements during the preparatory phase of batting. *Percept Mot Skills, 94*, 380-386.

Keeffe, J. E., Jin, C. F., Weih, L. M., McCarty, C. A., & Taylor, H. R. (2002). Vision impairment and older drivers: who's driving? *Br J Ophthalmol, 86*(10), 1118-1121.

Kempermann, G., Kuhn, H., & Gage, F. (1998). Experience-induced neurogenesis in the senescent dentate gyrus. *Journal of Neuroscience, 18*(9), 3206.

Kempermann, G., Kuhn, H. G., & Gage, F. H. (1997). More hippocampal neurons in adult mice living in an enriched environment. *Nature, 386*(6624), 493-495.

Ker, K., Roberts, I., Collier, T., Beyer, F., Bunn, F., & Frost, C. (2005). Post-licence driver education for the prevention of road traffic crashes: a systematic review of randomised controlled trials. *Accid Anal Prev, 37*(2), 305-313.

Kerr, C. E., Shaw, J. R., Wasserman, R. H., Chen, V. W., Kanojia, A., Bayer, T., et al. (2008). Tactile acuity in experienced Tai Chi practitioners: evidence for use dependent plasticity as an effect of sensory-attentional training. *Exp Brain Res, 188*(2), 317-322.

Kesaniemi, Y. K., Danforth, E., Jr., Jensen, M. D., Kopelman, P. G., Lefebvre, P., & Reeder, B. A. (2001). Dose-response issues concerning physical activity and health: an evidence-based symposium. *Med Sci Sports Exerc, 33*(6 Suppl), S351-358.

Keskinen, E., Ota, H., & Katila, A. (1998). Older drivers fail in intersections: speed discrepancies between older and younger male drivers. *Accid Anal Prev, 30*(3), 323-330.

Klavora, P., & Heslegrave, R. (2002). Senior drivers: an overview of problems and intervention strategies. *J Aging Phys Act, 10*, 322-335.

Kleim, J. A., Lussnig, E., Schwarz, E. R., Comery, T. A., & Greenough, W. T. (1996). Synaptogenesis and Fos expression in the motor cortex of the adult rat after motor skill learning. *J Neurosci, 16*(14), 4529-4535.

Kleim, J. A., Vij, K., Ballard, D. H., & Greenough, W. T. (1997). Learning-dependent synaptic modifications in the cerebellar cortex of the adult rat persist for at least four weeks. *J Neurosci, 17*(2), 717-721.

Klintsova, A., Cowell, R., Swain, R., Napper, R., Goodlett, C., & Greenough, W. (1998). Therapeutic effects of complex motor training on motor performance deficits induced by neonatal binge-like alcohol exposure in rats:: I. Behavioral results. *Brain research, 800*(1), 48-61.

Koga, Y., & Morandt, G. (1923). On the degree of association between reaction times in the case of different senses. *Biometrika, 15*, 346-372.

Kohn, M., & Schooler, C. (1983). *Work and personality: An inquiry into the impact of social stratification*: Ablex Pub.

Kooijman, C., Brouwer, W. H., Coeckelbergh, T. R., Tant, M. L., Cornelissen, F. W., Bredewoud, R. A., et al. (2004). Compensatory viewing training improves practical fitness to drive of subjects with impaired vision. *Visual Impairment Research, 6*(1), 1-27.

Kornack, D. R., & Rakic, P. (2001). Cell proliferation without neurogenesis in adult primate neocortex. *Science, 294*(5549), 2127-2130.

Kozorovitskiy, Y., Gross, C. G., Kopil, C., Battaglia, L., McBreen, M., Stranahan, A. M., et al. (2005). Experience induces structural and biochemical changes in the adult primate brain. *Proc Natl Acad Sci U S A, 102*(48), 17478-17482.

Kramer, A., Bherer, L., Colcombe, S., Dong, W., & Greenough, W. (2004). Environmental influences on cognitive and brain plasticity during aging. *J Gerontol A Biol Sci Med Sci, 59*(9), M940.

Kramer, A., Larish, J., & Strayer, D. (1995). Training for attention control in dual task settings: A comparison of young and old adults. *J Exp Psychol Appl, 1*, 50-76.

Kramer, A., Larish, J., Weber, T., & Bardell, L. (1999). Training for executive control: Task coordination strategies and aging. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII* (pp. 617-652). Cambridge, MA: MIT Press.

Kramer, A. F., Colcombe, S., Erickson, K., Belopolsky, A., McAuley, E., Cohen, N. J., et al. (2002). Effects of aerobic fitness training on human cortical function: a proposal. *J Mol Neurosci, 19*(1-2), 227-231.

Kramer, A. F., & Morrow, D. (in press). Cognitive Aging: A Primer. In D. Park & N. Schwartz (Eds.), *Cognitive Aging: A Primer*. Philadelphia, PA: Psychology Press.

Krampe, R. T. (2002). Aging, expertise and fine motor movement. *Neurosci Biobehav Rev, 26*(7), 769-776.

Krampe, R. T., & Erickson, K. A. (1996). Maintaining excellence: Deliberate practice and elite performance in younger and older pianists. *J Exp Psychol Gen, 125*, 331-359.

Kua, A., Korner-Bitensky, N., Desrosiers, J., Man-Son-Hing, M., & Marshall, S. (2007). Older driver retraining: a systematic review of evidence of effectiveness. *J Safety Res, 38*(1), 81-90.

Kuramoto, A. M. (2006). Therapeutic benefits of Tai Chi exercise: research review. *Wmj, 105*(7), 42-46.

Kutner, N. G., Barnhart, H., Wolf, S. L., McNeely, E., & Xu, T. (1997). Self-report benefits of Tai Chi practice by older adults. *J Gerontol B Psychol Sci Soc Sci, 52*(5), P242-246.

Leung, S., & Starmer, G. (2005). Gap acceptance and risk-taking by young and mature drivers, both sober and alcohol-intoxicated, in a simulated driving task. *Accid Anal Prev, 37*(6), 1056-1065.

Li, G., Braver, E. R., & Chen, L. H. (2003). Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. *Accid Anal Prev, 35*(2), 227-235.

Lobjois, R., Benguigui, N., Bertsch, J., & Broderick, M. P. (2008). Collision avoidance behavior as a function of aging and tennis playing. *Exp Brain Res, 184*(4), 457-468.

Luchies, C. W., Schiffman, J., Richards, L. G., Thompson, M. R., Bazuin, D., & DeYoung, A. J. (2002). Effects of age, step direction, and reaction condition on the ability to step quickly. *J Gerontol A Biol Sci Med Sci, 57*(4), M246-249.

Lum, J., Enns, J. T., & Pratt, J. (2002). Visual orienting in college athletes: explorations of athlete type and gender. *Res Q Exerc Sport, 73*(2), 156-167.

Lyman, J. M., McGwin, G., Jr., & Sims, R. V. (2001). Factors related to driving difficulty and habits in older drivers. *Accid Anal Prev, 33*(3), 413-421.

Lyman, S., Ferguson, S. A., Braver, E. R., & Williams, A. F. (2002). Older driver involvements in police reported crashes and fatal crashes: trends and projections. *Inj Prev, 8*(2), 116-120.

Magill, R. (2003). *Motor Learning and control, concepts and applications* (Seventh ed.). New York: McGraw-Hill.

Magladery, J. (1959). Neurophysiology of aging. In J. E. Birren (Ed.), *Handbook of Aging and the Individual* (pp. 173-186). Chicago: Univ. Chigaco Press.

Makishita, H., & Matsunaga, K. (2008). Differences of drivers' reaction times according to age and mental workload. *Accid Anal Prev, 40*(2), 567-575.

Mangal, S. (2007). *Essentials of educational psychology*. Connaught Circos, New Delhi: Prentice-Hall of India.

Mann, D. T., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: a meta-analysis. *J Sport Exerc Psychol, 29*(4), 457-478.

Manning, C. A., Ragozzino, M. E., & Gold, P. E. (1993). Glucose enhancement of memory in patients with probable senile dementia of the Alzheimer's type. *Neurobiol Aging, 14*(6), 523-528.

Manning, C. A., Stone, W. S., Korol, D. L., & Gold, P. E. (1998). Glucose enhancement of 24-h memory retrieval in healthy elderly humans. *Behav Brain Res, 93*(1-2), 71-76.

Manser, M. P., & Hancock, P. A. (1996). Influence of approach angle on estimates of Time to-Contact. *Ecological Psychology, 8*(1), 71-99.

Markham, J. A., & Greenough, W. T. (2004). Experience-driven brain plasticity: beyond the synapse. *Neuron Glia Biol, 1*(4), 351-363.

Markowska, A. L., Mooney, M., & Sonntag, W. E. (1998). Insulin-like growth factor-1 ameliorates age-related behavioral deficits. *Neuroscience, 87*(3), 559-569.

Marks, B. L. (2006). Health benefits for veteran (senior) tennis players. *Br J Sports Med, 40*(5), 469-476; discussion 476.

Marks, B. L., Katz, L. M., & Nunley, D. C. (2000). Cerebral blood flow and cognitive function is maintained in aerobically active older adults. *Circulation, 102* (suppl 18), II-875.

Marmeleira, J., Ferreira, I., Godinho, M., & Fernandes, O. (2007). *Time to arrival and useful field of view: associations with reported driving difficulties among older adults.* Paper presented at the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design., Stevenson, Washington.

Marmeleira, J., Godinho, M., & Fernandes, O. (2009). The effects of an exercise program on several abilities associated with driving performance in older adults. *Accident Analysis and Prevention*, *41*(21), 90-97.

Marmeleira, J., Godinho, M., Malarranha, F., & Fernandes, O. Effects of age in Useful Field of View and Time-to-Arrival. *Adv Transport Stud, 17*, 29-38.

Marottoli, R. A., Allore, H., Araujo, K. L., Iannone, L. P., Acampora, D., Gottschalk, M., et al. (2007). A randomized trial of a physical conditioning program to enhance the driving performance of older persons. *J Gen Intern Med, 22*(5), 590-597.

Marottoli, R. A., Cooney, L. M., Jr., Wagner, R., Doucette, J., & Tinetti, M. E. (1994). Predictors of automobile crashes and moving violations among elderly drivers. *Ann Intern Med, 121*(11), 842-846.

Marottoli, R. A., de Leon, C. F. M., Glass, T. A., Williams, C. S., Cooney, L. M., Jr., & Berkman, L. F. (2000). Consequences of driving cessation: decreased out-of-home activity levels. *J Gerontol B Psychol Sci Soc Sci, 55*(6), S334-340.

Marottoli, R. A., & Drickamer, M. A. (1993). Psychomotor mobility and the elderly driver. *Clin Geriatr Med, 9*(2), 403-411.

Marottoli, R. A., Ness, P. H., Araujo, K. L., Iannone, L. P., Acampora, D., Charpentier, P., et al. (2007). A randomized trial of an education program to enhance older driver performance. *J Gerontol A Biol Sci Med Sci, 62*(10), 1113-1119.

Marottoli, R. A., Richardson, E. D., Stowe, M. H., Miller, E. G., Brass, L. M., Cooney, L. M., Jr., et al. (1998). Development of a test battery to identify older drivers at risk for self-reported adverse driving events. *J Am Geriatr Soc, 46*(5), 562-568.

Matos, R., & Godinho, M. (2005). Transfer of Useful Field of Vision from Team Sports to Driving Skills in a Simulated Driving Test. In L. Dorn (Ed.), *Driver behaviour and training* (Vol. II, pp. 459-470). Hamshire: Asghate Publishing Limited.

Matos, R., & Godinho, M. (2007). Useful field of vision and peripheral reaction time in novice drivers: transfer to a real driving situation after a perceptual-motor training program. *Adv Transp Stud, in press*.

Matos, R., & Godinho, M. (2009). Useful field of vision and peripheral reaction time in novice drivers: transfer to a real driving situation after a perceptual-motor training program. *Adv Transp Stud, 19*, 77-84.

Mayhew, D. R., Simpson, H. M., & Ferguson, S. A. (2006). Collisions involving senior drivers: high-risk conditions and locations. *Traffic Inj Prev, 7*(2), 117-124.

McAuley, E., & Elavsky, S. (2008). Self-efficacy, physical activity, and cognitive function. In W. W. Spirduso, L. W. Poon & Chodzko-Zajko (Eds.), *Exercise and its mediating effects on cognition* (pp. 69-84). Champaign, IL: Human Kinetics.

McAuliffe, J. (2004). Differences in attentional set between athletes and nonathletes. *J Gen Psychol, 131*(4), 426-437.

McDowd, J. M., & Craik, F. I. (1988). Effects of aging and task difficulty on divided attention performance. *J Exp Psychol Hum Percept Perform, 14*(2), 267-280.

McFarland, R. A. (1963). Experimental evidence of the relantioship between aging and oxygen want: In search of a theory of aging. *Ergonomics, 6*, 339-366.

McGwin, G., Jr., & Brown, D. B. (1999). Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accid Anal Prev, 31*(3), 181-198.

McGwin, G., Jr., Sims, R. V., Pulley, L., & Roseman, J. M. (2000). Relations among chronic medical conditions, medications, and automobile crashes in the elderly: a population-based case-control study. *Am J Epidemiol, 152*(5), 424-431.

McKnight, A. J., & McKnight, A. S. (1999). Multivariate analysis of age-related driver ability and performance deficits. *Accid Anal Prev, 31*(5), 445-454.

McMorris, T. (2009). Exercise and cognitive function: a neuroendocrinological explanation. In T. McMorris, P. Tomporowsky & M. Audiffren (Eds.), *Exercise and Cognitive Function* (pp. 41-68). Chichester, West Sussex, UK: Willey & Blackwell.

Meeusen, R. (2005). Exercise and the brain: insight in new therapeutic modalities. *Ann Transplant, 10*(4), 49-51.

Meeusen, R., Piacentini, M. F., & De Meirleir, K. (2001). Brain microdialysis in exercise research. *Sports Med, 31*(14), 965-983.

Meeusen, R., Smolders, I., Sarre, S., De Meirleir, K., Keizer, H., Serneels, M., et al. (1997). Endurance training effects on neurotransmitter release in rat striatum: an in vivo microdialysis study. *Acta Physiol Scand, 159*(4), 335-341.

Meyer, J. S., Terayama, Y., & Takashima, S. (1993). Cerebral circulation in the elderly. *Cerebrovasc Brain Metab Rev, 5*(2), 122-146.

Mizoguchi, K., Shoji, H., Tanaka, Y., Maruyama, W., & Tabira, T. (2009). Age-related spatial working memory impairment is caused by prefrontal cortical dopaminergic dysfunction in rats. *Neuroscience, 162*(4), 1192-1201.

Mohammed, A., Zhu, S., Darmopil, S., Hjerling-Leffler, J., Ernfors, P., Winblad, B., et al. (2002). Environmental enrichment and the brain. *Prog brain res, 138*, 109.

Morrison, R. W., Swope, J. G., & Halcomb, C. G. (1986). Movement time and brake pedal placement. *Hum Factors, 28*(2), 241-246.

Moss, M., Franks, M., Briggs, P., Kennedy, D., & Scholey, A. (2005). Compromised arterial oxygen saturation in elderly asthma sufferers results in selective cognitive impairment. *J Clin Exp Neuropsychol, 27*(2), 139-150.

Neeper, S. A., Gomez-Pinilla, F., Choi, J., & Cotman, C. (1995). Exercise and brain neurotrophins. *Nature, 373*(6510), 109.

Nicoletti, G., Arabia, G., Pugliese, P., Torchia, G., Pucci, F., Gambardella, A., et al. (2005). Movement time and aging: a normative study in healthy subjects with the "Movement Time Analyzer". *Aging Clin Exp Res, 17*(3), 207-210.

Oken, B. S., Zajdel, D., Kishiyama, S., Flegal, K., Dehen, C., Haas, M., et al. (2006). Randomized, controlled, six-month trial of yoga in healthy seniors: effects on cognition and quality of life. *Altern Ther Health Med, 12*(1), 40-47.

Olson, A. K., Eadie, B. D., Ernst, C., & Christie, B. R. (2006). Environmental enrichment and voluntary exercise massively increase neurogenesis in the adult hippocampus via dissociable pathways. *Hippocampus, 16*(3), 250-260.

Olson, P., & Dewar, R. (2007). Introduction. In R. Dewar & P. Olson (Eds.), *Human factors in traffic safety* (pp. 1-7). Tucson: Lawyers & Judges Publishing Co., Inc.

Ostrow, A. C., Shaffron, P., & McPherson, K. (1992). The effects of a joint range-of-motion physical fitness training program on the automobile driving skills of older adults. *J Safety Res, 23*, 207-219.

Owsley, C., Ball, K., McGwin, G., Jr., Sloane, M. E., Roenker, D. L., White, M. F., et al. (1998). Visual processing impairment and risk of motor vehicle crash among older adults. *JAMA, 279*(14), 1083-1088.

Owsley, C., Ball, K., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1991). Visual/cognitive correlates of vehicle accidents in older drivers. *Psychol Aging, 6*(3), 403-415.

Owsley, C., McGwin, G., Jr., Phillips, J. M., McNeal, S. F., & Stalvey, B. T. (2004). Impact of an educational program on the safety of high-risk, visually impaired, older drivers. *Am J Prev Med, 26*(3), 222-229.

Owsley, C., Stalvey, B. T., Wells, J., Sloane, M. E., & McGwin, G., Jr. (2001). Visual risk factors for crash involvement in older drivers with cataract. *Arch Ophthalmol, 119*(6), 881-887.

Panton, L. B., Graves, J. E., Pollock, M. L., Hagberg, J. M., & Chen, W. (1990). Effects of aerobic and resistance training on fractioned reaction time and speed of movement. *Journal of Gerontology: Medical Sciences, 45*, M26-31.

Pereira, A. C., Huddleston, D. E., Brickman, A. M., Sosunov, A. A., Hen, R., McKhann, G. M., et al. (2007). An in vivo correlate of exercise-induced neurogenesis in the adult dentate gyrus. *Proc Natl Acad Sci U S A, 104*(13), 5638-5643.

Pesce, C., Cereatti, L., Casella, R., Baldari, C., & Capranica, L. (2007). Preservation of visual attention in older expert orienteers at rest and under physical effort. *J Sport Exerc Psychol, 29*(1), 78-99.

Podewils, L. J., Guallar, E., Kuller, L. H., Fried, L. P., Lopez, O. L., Carlson, M., et al. (2005). Physical activity, APOE genotype, and dementia risk: findings from the Cardiovascular Health Cognition Study. *Am J Epidemiol, 161*(7), 639-651.

Poon, L. W., & Harrington, C. A. (2006). Commonalities in aging and fitness-related impact on cognition. In L. W. Poon, W. Chodzko-Zajko & P. D. Tomporowski (Eds.), *Active living, Cognitive Functioning and Aging* (pp. 187-195). Champaign: Human Kinetics.

Preusser, D. F., Williams, A. F., Ferguson, S. A., Ulmer, R. G., & Weinstein, H. B. (1998). Fatal crash risk for older drivers at intersections. *Accid Anal Prev, 30*(2), 151-159.

Raghuram, A., & Lakshminarayanan, V. (2006). Motion perceptions tasks as potential correlates to driving difficulty in the elderly. *J Mod Optic 53*(9), 1343-1362.

Rampon, C., & Tsien, J. Z. (2000). Genetic analysis of learning behavior-induced structural plasticity. *Hippocampus, 10*(5), 605-609.

Recarte, M. A., & Nunes, L. M. (2003). Mental workload while driving: effects on visual search, discrimination, and decision making. *J Exp Psychol Appl, 9*(2), 119-137.

Reger, M. A., Welsh, R. K., Watson, G. S., Cholerton, B., Baker, L. D., & Craft, S. (2004). The relationship between neuropsychological functioning and driving ability in dementia: a meta-analysis. *Neuropsychology, 18*(1), 85-93.

Richardson, E. D., & Marottoli, R. A. (2003). Visual attention and driving behaviors among community-living older persons. *J Gerontol A Biol Sci Med Sci, 58*(9), M832-836.

Rockwood, K., & Middleton, L. (2008). Physical activity and the maintenance of cognitive function. *Alzheimer's and Dementia 3*(2), S38-S44.

Roenker, D. L., Cissell, G. M., Ball, K. K., Wadley, V. G., & Edwards, J. D. (2003). Speed-of-processing and driving simulator training result in improved driving performance. *Hum Factors, 45*(2), 218-233.

Rogé, J., Otmani, S., Pébayle, T., & Muzet, A. (2008). The impact of age on useful visual field deterioration and risk evaluation in a simulated driving task. *Eur Rev Appl Psychol 58*, 5-12.

Rogers, R. L., Meyer, J. S., & Mortel, K. F. (1990). After reaching retirement age physical activity sustains cerebral perfusion and cognition. *J Am Geriatr Soc, 38*(2), 123-128.

Rosenbloom, S. (1993). Transportation needs of the elderly population. *Clin Geriatr Med, 9*(2), 297-310.

Rosenbloom, S. (2001). Sustainability and automobility among the elderly: An international assessment. *Transportation, 28*, 375-408.

Rosenzweig, M. R., & Bennett, E. L. (1996). Psychobiology of plasticity: effects of training and experience on brain and behavior. *Behav Brain Res, 78*(1), 57-65.

Roth, D. L., Goode, K. T., Clay, O. J., & Ball, K. K. (2003). Association of physical activity and visual attention in older adults. *J Aging Health, 15*(3), 534-547.

Rubin, G. S., Ng, E. S., Bandeen-Roche, K., Keyl, P. M., Freeman, E. E., & West, S. K. (2007). A prospective, population-based study of the role of visual impairment in motor vehicle crashes among older drivers: the SEE study. *Invest Ophthalmol Vis Sci, 48*(4), 1483-1491.

Sachs-Ericsson, N., Joiner, T., Plant, E., & Blazer, D. (2005). The influence of depression on cognitive decline in community-dwelling elderly persons. *Am J Geriatr Psychiatry, 13*(5), 402.

Sagberg, F. (2006). Driver health and crash involvement: a case-control study. *Accid Anal Prev, 38*(1), 28-34.

Salthouse, T. (2006). Mental Exercise and Mental Aging. Evaluating the Validity of the ‘‘Use It or Lose It’’ Hypothesis. *Perspect Psychol Sci, 1*(1), 68-87.

Salthouse, T. A. (1985). Speed of behavior and its implications for cognition. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (2nd ed., pp. 400-426). New York: Van Nostrand Reinhold.

Salthouse, T. A. (1993). Attentional blocks are not responsible for age-related slowing. *J Gerontol, 48*(6), P263-270.

Salthouse, T. A. (2000). Aging and measures of processing speed. *Biol Psychol, 54*(1-3), 35-54.

Salthouse, T. A., Berish, D. E., & Miles, J. D. (2002). The role of cognitive stimulation on the relations between age and cognitive functioning. *Psychol Aging, 17*(4), 548-557.

Sanders, A. F. (1970). Some aspects of the selective process in the functional visual field. *Ergonomics, 13*(1), 101-117.

Schiff, W., Oldak, R., & Shah, V. (1992). Aging persons' estimates of vehicular motion. *Psychol Aging, 7*(4), 518-525.

Schmidt, R., & Lee, T. (2005). *Motor control and learning: A behavioral emphasis*: Human Kinetics Publishers.

Scholey, A. B., Moss, M. C., Neave, N., & Wesnes, K. (1999). Cognitive performance, hyperoxia, and heart rate following oxygen administration in healthy young adults. *Physiol Behav, 67*(5), 783-789.

Schooler, C. (2009). The effects of the cognitive complexity of occupational conditions and leisure-time activities on the intellectual functioning of older adults. In W. Chodzko-Zajko, A. Kramer & L. W. Poon (Eds.), *Enhancing cognitive functioning and brain plasticity* (Vol. 3, pp. 15-34). Champaign, IL: Human Kinetics.

Schweitzer, N., Apter, Y., Ben-David, G., Liebermann, D. G., & Parush, A. (1995). A field study on braking responses during driving: II. Minimum driver brake times. *Ergonomics, 38*(9), 1903-1910.

Segovia, G., del Arco, A., & Mora, F. (2009). Environmental enrichment, prefrontal cortex, stress, and aging of the brain. *J Neural Transm, 116*(8), 1007-1016.

Seidler, R. D., Bernard, J. A., Burutolu, T. B., Fling, B. W., Gordon, M. T., Gwin, J. T., et al. (2010). Motor control and aging: Links to age-related brain structural, functional, and biochemical effects. *Neurosci Biobehav Rev*. *34*(5), 721-733.

Seiple, W., Szlyk, J. P., Yang, S., & Holopigian, K. (1996). Age-related functional field losses are not eccentricity dependent. *Vision Res, 36*(12), 1859-1866.

Sekuler, A. B., Bennett, P. J., & Mamelak, M. (2000). Effects of aging on the useful field of view. *Exp Aging Res, 26*(2), 103-120.

Shay, K. A., & Roth, D. L. (1992). Association between aerobic fitness and visuospatial performance in healthy older adults. *Psychol Aging, 7*(1), 15-24.

Shea, C. H., Park, J. H., & Braden, H. W. (2006). Age-related effects in sequential motor learning. *Phys Ther, 86*(4), 478-488.

Sifrit, K., Chaparro, A., Groff, L., & Stumpfhauser, L. (2001). *Effects of visual attention training on situational awareness in a simulated driving task.* Paper presented at the Meeting of the Association for Research in Vision and Ophthalmology, Fort Lauderdale, FL.

Sifrit, K., Chaparro, A., & Stumpfhauser, L. (2003). *Improving visual attention in older drivers.* Paper presented at the Human Factors and Ergonomics Society 47th Annual Meeting Santa Monica, CA.

Silverman, I. W. (2006). Sex differences in simple visual reaction time: a historical meta-analysis. *Sex Roles: A Journal of Research, 54*(1-2), 57-69.

Simões, A. (2003). The cognitive training needs of older drivers. *Recherche, Transports, Sécurité 79*, 145-155.

Sims, R. V., McGwin, G., Jr., Allman, R. M., Ball, K., & Owsley, C. (2000). Exploratory study of incident vehicle crashes among older drivers. *J Gerontol A Biol Sci Med Sci, 55*(1), M22-27.

Sims, R. V., McGwin, G., Jr., Pulley, L. V., & Roseman, J. M. (2001). Mobility impairments in crash-involved older drivers. *J Aging Health, 13*(3), 430-438.

Sims, R. V., Owsley, C., Allman, R. M., Ball, K., & Smoot, T. M. (1998). A preliminary assessment of the medical and functional factors associated with vehicle crashes by older adults. *J Am Geriatr Soc, 46*(5), 556-561.

Skaar, N., Rizzo, M., & Stierman, L. (2003). *Traffic entry judgments by aging drivers.* Paper presented at the Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Park City, Utah.

Slegers, K., van Boxtel, M., & Jolles, J. (2006). *Successful Cognitive Aging: The use of computers and the Internet to support autonomy in later life* Maastricht: Neuropsych Publishers.

Slosman, D. O., Chicherio, C., Ludwig, C., Genton, L., de Ribaupierre, S., Hans, D., et al. (2001). (133)Xe SPECT cerebral blood flow study in a healthy population: determination of T-scores. *J Nucl Med, 42*(6), 864-870.

Smeeton, N. J., Williams, A. M., Hodges, N. J., & Ward, P. (2005). The relative effectiveness of various instructional approaches in developing anticipation skill. *J Exp Psychol Appl, 11*(2), 98-110.

Smith, C. D., Umberger, G. H., Manning, E. L., Slevin, J. T., Wekstein, D. R., Schmitt, F. A., et al. (1999). Critical decline in fine motor hand movements in human aging. *Neurology, 53*(7), 1458-1461.

Smulders, F. T., Kenemans, J. L., Schmidt, W. F., & Kok, A. (1999). Effects of task complexity in young and old adults: reaction time and P300 latency are not always dissociated. *Psychophysiology, 36*(1), 118-125.

Spirduso, W. W. (1980). Physical fitness, aging, and psychomotor speed: a review. *J Gerontol, 35*(6), 850-865.

Spirduso, W. W. (2006). Issues of aging, physical activity, cognition and putative mechanisms for a relationship: a discussion. In L. W. Poon, W. Chodzko-Zajko & P. D. Tomporowski (Eds.), *Active living, Cognitive Functioning and Aging* (pp. 187-195). Champaign: Human Kinetics.

Spirduso, W. W., & Clifford, P. (1978). Replication of age and physical activity effects on reaction and movement time. *J Gerontol, 33*(1), 26-30.

Spirduso, W. W., Francis, K. L., & MacRae, P. G. (2005). *Physical Dimensions of Aging-2nd Edition*. Champaign, IL: Human Kinetics.

Stelmach, G. E., & Nahom, A. (1992). Cognitive-motor abilities of the elderly driver. *Hum Factors, 34*(1), 53-65.

Stutts, J. C. (1998). Do older drivers with visual and cognitive impairments drive less? *J Am Geriatr Soc, 46*(7), 854-861.

Swaab, D. F. (1991). Brain aging and Alzheimer's disease, "wear and tear" versus "use it or lose it". *Neurobiol Aging, 12*(4), 317-324.

Swain, R. A., Harris, A. B., Wiener, E. C., Dutka, M. V., Morris, H. D., Theien, B. E., et al. (2003). Prolonged exercise induces angiogenesis and increases cerebral blood volume in primary motor cortex of the rat. *Neuroscience, 117*(4), 1037-1046.

Takada, H., Nagata, K., Hirata, Y., Satoh, Y., Watahiki, Y., Sugawara, J., et al. (1992). Age-related decline of cerebral oxygen metabolism in normal population detected with positron emission tomography. *Neurol Res, 14*(2 Suppl), 128-131.

Tay, R. (2006). Ageing drivers: storm in a teacup? *Accid Anal Prev, 38*(1), 112-121.

Thorndike, E., & Woodworth, R. (1901). The influence of improvement in one mental function upon the efficiency of other functions. II. The estimation of magnitudes. *Psychological Review, 8*(4), 384-395.

Tomporowski, P. D. (1997). The effects of physical and mental training on the mental abibilities of older adults. *J aging phys act, 5*, 9-26.

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychol (Amst), 112*(3), 297-324.

Tranter, L. J., & Koutstaal, W. (2008). Age and flexible thinking: an experimental demonstration of the beneficial effects of increased cognitively stimulating activity on fluid intelligence in healthy older adults. *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn, 15*(2), 184-207.

Tuokko, H., Tallman, K., Beattie, B. L., Cooper, P., & Weir, J. (1995). An examination of driving records in a dementia clinic. *J Gerontol B Psychol Sci Soc Sci, 50*(3), S173-181.

Tuokko, H. A., Rhodes, R. E., & Dean, R. (2007). Health conditions, health symptoms and driving difficulties in older adults. *Age Ageing, 36*(4), 389-394.

van Boxtel, M. P., Paas, F. G., Houx, P. J., Adam, J. J., Teeken, J. C., & Jolles, J. (1997). Aerobic capacity and cognitive performance in a cross-sectional aging study. *Med Sci Sports Exerc, 29*(10), 1357-1365.

van Praag, H. (2008). Neurogenesis and exercise: past and future directions. *Neuromolecular Med, 10*(2), 128-140.

van Praag, H., Christie, B. R., Sejnowski, T. J., & Gage, F. H. (1999). Running enhances neurogenesis, learning, and long-term potentiation in mice. *Proc Natl Acad Sci U S A, 96*(23), 13427-13431.

van Praag, H., Kempermann, G., & Gage, F. H. (2000). Neural consequences of environmental enrichment. *Nat Rev Neurosci, 1*(3), 191-198.

van Praag, H., Shubert, T., Zhao, C., & Gage, F. (2005). Exercise enhances learning and hippocampal neurogenesis in aged mice. *Journal of Neuroscience, 25*(38), 8680.

Vance, D. E., Roenker, D. L., Cissell, G. M., Edwards, J. D., Wadley, V. G., & Ball, K. K. (2006). Predictors of driving exposure and avoidance in a field study of older drivers from the state of Maryland. *Accid Anal Prev, 38*(4), 823-831.

Vaynman, S., Ying, Z., & Gomez-Pinilla, F. (2004). Hippocampal BDNF mediates the efficacy of exercise on synaptic plasticity and cognition. *Eur J Neurosci, 20*(10), 2580-2590.

Voss, M., Kramer, A., Basak, C., Prakash, R., & Roberts, B. (2009). Are expert athletes expert in the cognitive laboratory? A meta-analytic review of cognition and sport expertise. *Appl Cogn Psych*.

Waller, P. F. (1991). The older driver. *Hum Factors, 33*(5), 499-505.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychol Bull, 120*(2), 272-292.

Whelihan, W. M., DiCarlo, M. A., & Paul, R. H. (2005). The relationship of neuropsychological functioning to driving competence in older persons with early cognitive decline. *Arch Clin Neuropsychol, 20*(2), 217-228.

Williams, A., Davids, K., & Williams, J. G. (1999). *Visual perception and action in sport*. London: Taylor & Francis.

Williams, A. F. (1989). Driver age and crash involvement. *Am J Public Health, 79*, 326-327.

Williams, A. M., Ward, P., Knowles, J. M., & Smeeton, N. J. (2002). Anticipation skill in a real-world task: measurement, training, and transfer in tennis. *J Exp Psychol Appl, 8*(4), 259-270.

Williams, J., & Thirer, J. (1975). Vertical and horizontal peripheral vision in male and female athletes and nonathletes. *Research quarterly, 46*(2), 200.

Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M., et al. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. *JAMA, 296*(23), 2805-2814.

Winter, B., Breitenstein, C., Mooren, F. C., Voelker, K., Fobker, M., Lechtermann, A., et al. (2007). High impact running improves learning. *Neurobiol Learn Mem, 87*(4), 597-609.

Wolinsky, F. D., Unverzagt, F. W., Smith, D. M., Jones, R., Stoddard, A., & Tennstedt, S. L. (2006). The ACTIVE cognitive training trial and health-related quality of life: protection that lasts for 5 years. *J Gerontol A Biol Sci Med Sci, 61*(12), 1324-1329.

Wolinsky, F. D., Unverzagt, F. W., Smith, D. M., Jones, R., Wright, E., & Tennstedt, S. L. (2006). The effects of the ACTIVE cognitive training trial on clinically relevant declines in health-related quality of life. *J Gerontol B Psychol Sci Soc Sci, 61*(5), S281-287.

Woodlee, M., & Schallert, T. (2006). The impact of motor activity and inactivity on the brain. *Curr Dir Psychol Sci, 15*(4), 203.

World Health Organization (1997). The Heidelberg Guidelines for Promoting Physical Activity among Older Persons. *J Aging Phys Act, 5*, 2-8.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strenght of stimulus to rapidity of habit-formation. *J Comp Neurol Psychol, 18*, 459-482.

Zhang, L., Baldwin, K., Munoz, B., Munro, C., Turano, K., Hassan, S., et al. (2007). Visual and cognitive predictors of performance on brake reaction test: Salisbury eye evaluation driving study. *Ophthalmic Epidemiol, 14*(4), 216-222.

Zheng, H., Liu, Y., Li, W., Yang, B., Chen, D., Wang, X., et al. (2006). Beneficial effects of exercise and its molecular mechanisms on depression in rats. *Behav Brain Res, 168*(1), 47-55.

Zoladz, J. A., Pilc, A., Majerczak, J., Grandys, M., Zapart-Bukowska, J., & Duda, K. (2008). Endurance training increases plasma brain-derived neurotrophic factor concentration in young healthy men. *J Physiol Pharmacol, 59 Suppl 7*, 119-132.

Zunzunegui, M., Alvarado, B., Del Ser, T., & Otero, A. (2003). Social networks, social integration, and social engagement determine cognitive decline in community-dwelling Spanish older adults. *J Gerontol B Psychol Sci Soc Sci 58*(2), 93.

CHAPTER II

Methodology

A description of two important aspects of the methods used is presented in this chapter: (i) the exercise program of the experimental studies and (ii) the instrumentation created for driving assessment. A summary of the methods used across this thesis is given in Table 1. Other relevant information is presented in the appropriate sections of each article.

1.A specific exercise program to promote driving ability in older adults

Several factors (e.g., vision, health and physical performance) have been associated with driving ability in older adults. Among them, cognitive performance may be the strongest predictor of driving mobility. Research has shown that older adults' cognitive performance (e.g., visual attention) is positively influenced by physical exercise or mental exercise (Bherer, et al., 2008; Roth, Goode, Clay, & Ball, 2003). The *cardiovascular fitness hypothesis* has been the most recognized hypothesis for explaining the positive association between PA and cognition (Smiley-Oyen, Lowry, Francois, Kohut, & Ekkekakis, 2008). A growing body of evidence demonstrates that cognitive training can reduce or eliminate the deficits observed in a variety of perceptual and cognitive processes during the course of aging (Ball, Wadley, Vance, & Edwards, 2004; Hultsch, Hertzog, Small, & Dixon, 1999). In spite of this, few studies have addressed the issue of whether and to what extent the association between physical and mental training improves the cognitive functioning of older individuals (Pesce, Cereatti, Casella, Baldari, & Capranica, 2007). Exploring this idea, Fabre et al. (2002) concluded that combined aerobic and mental training could lead to greater effects in cognitive than either technique alone. Furthermore, it was recently reported that an exercise program that targets specific perceptive-motor abilities was capable of enhancing visual attention and other relevant abilities for driving performance and safety in younger drivers (Matos & Godinho, 2009).

Regardless of the few exceptions already mentioned, the research on the relationship between PA and cognition in older adults has mainly examined the effects of unskilled motor movements or automatized skills (e.g., walking and swimming). However, based on the literature reviewed, it seems reasonable to hypothesize that PA, which exert large cognitive demands, could have a higher impact on cognition. If combined training (aerobic and mental training) could lead to greater effects on cognitive performance (or at least for some cognitive abilities) than either technique alone then perhaps exercise programs could be designed to merge these different types of stimulation. In this case, the exercise intervention should be planned to stress not only physiological systems, but also perceptive and cognitive mechanisms.

The type of exercise intervention proposed and tested in this thesis could not be considered multimodal in the common view of a program with two distinct parts (mental exercise and physical exercise) that are implemented side-by-side with the goal of improve cognitive functioning in older adults. The type of program that this research advocates is clearly a physical exercise program, where cognitively challenging tasks are executed by the older adults employing physical activities like walking, stepping, reaching, throwing, and manipulating objects. For example, it has been proposed (Colcombe & Kramer, 2003; Kramer, et al., 2003) that exercise that results in gains in cardio-respiratory fitness leads to benefits in tasks with a substantial frontal-lobe-dependent executive control component. These are the cerebral areas that exhibit the largest age-related declines and are also the ones that show the largest exercise or fitness-related improvements. Tasks that are included in the executive functioning umbrella include those involving the use of information retained in working memory, simultaneous execution of multiple tasks, task switching, and inhibition of an ongoing or prepotent response. Considering these characteristics, the greatest gains in executive functioning might be achieved if the exercise training stimulates aerobic capability (and by this means promoting physiological adaptations such as higher blood prefusion and neurotransmissers turnover) and also incorporate behavioral tasks that directly stimulate executive control components (e.g., planning, inhibition and task switching). Additionally, it seems reasonable to consider that forms of exercise that incorporate activities that intend to enhance speed of behavior could have a higher impact on the individual’s capacity to respond quickly to environmental stimuli during actual driving. This idea is based on the hypothesis that for positive transfer to occur between training and transfer tasks, they must involve the same cognitive processing demands (Magill, 2003).

Because driving an automobile is a common task of daily living that requires motor and cognitive skills, it seems a perfect field to investigate the effects of a specific exercise program that simultaneously requires physical effort (e.g., aerobic capability) and mental effort (e.g., information processing speed and working memory) to produce the desired motor responses.

Table 1. Summary of the methodology used in the current thesis

Article	Design	Participants	Instruments and Tests	Main Variables	Statistics
1.*The potential role of physical activity on driving performance and safety among older adults*	Literature review	-	-	-	-
2.*Associations between physical activity and driving-related cognitive abilities in older drivers: an exploratory study*	Cross-sectional	38 drivers (61-81 years)	International PA Questionnaire UFOV® Trail Making Test, parts A and B Tower of London Rey-Osterrieth Complex Figure Test Block Design Mini-Mental State Examination Snellen Chart	MET-minute week[1] Visual Attention Executive Functioning Visuospatial Constructional Ability Memory	Partial correlations Z-scores
3.*Effects of age in Useful Field of View and Time-to-Arrival*	Cross-sectional	96 drivers: -32 young (18-30 years) -32 middle-aged (38-50 years) -32 older (60-75 years)	UFOV® Time-to-Arrival Mini-Mental State Examination Snellen Chart	Visual Attention Speed Perception	ANOVA Scheffé test Contrasts analysis Partial correlations Independent sample *t*-test
4.*The effects of an exercise program on several abilities associated with driving performance in older adults*	RCT	32 drivers: -exercise group (n=16, 60-81 years) -control group (n=16, 60-82 years)	Simple RT (single- and dual-task condition) Choice RT UFOV® Time-to-Arrival Trail Making Test, part B Stroop Color-Word Test Foot Tap Test Timed Up and Go Test Functional Reach Test Mini-Mental State Examination Snellen Chart	RT Visual Attention Executive Functioning Speed Perception Motor Performance	Kolmogorov-Smirnov test Independent sample *t*-test Paired sample *t*-test Mann-Whitney test Wilcoxon signed-rank test

Article	Design	Participants	Instruments and Tests	Main Variables	Statistics
5.*Exercise can improve speed of behavior in older adults*	RCT	26 drivers: -exercise group (n=13, 55-76 years) -control group (n=13, 57-78 years)	Brake RT Task (single- and dual-task condition) Choice RT Peripheral RT Mini-Mental State Examination Snellen Chart	Behavioral Speed	Shapiro-Wilk test Independent sample *t*-test Paired sample *t*-test ANCOVA Partial eta squared (η_p^2) Z-scores
6. *Tennis playing, but not running, can enhance speed of behavior in older drivers*	Cross-sectional	36 drivers: -long distance runners (n=12, 55-71 years) -tennis players (n=12, 55-76 years) -control group (n=12, 58-75 years)	Brake RT Task (single- and dual-Task condition) Choice RT Peripheral RT Mini-Mental State Examination Snellen Chart	Behavioral Speed	Shapiro-Wilk test ANOVA Scheffé test Independent sample *t*-test Z-scores

Note. MET, Metabolic Equivalent; PA, Physical Activity; RT, Reaction Time; UFOV®, Useful Field of View test; RCT, Randomized Control Trial.

1.2.Example of activities

Numerous exercises were incorporated into the exercise programs that were designed for the two experimental studies conducted in this thesis. In this section, some examples are given to illustrate the type of exercises performed. A brief description of each task, possible task variations, and targeted abilities are presented. In the targeted abilities topic, the main cognitive abilities that are thought to be involved in the performance of the tasks are described. Components of physical fitness are not described because they are implicit (especially the aerobic component) to the execution of the majority of tasks.

1.Maintaining several balloons in the air (Fig. 1.1)

Task variations

-Executing the task individually with two balloons
-While maintaining balloons in the air, all auditory numeric signs but one require rapidly catching specific colored balloons
-Executing the task with the participants moving from one side of the gymnasium to the other (team competition could be used)

Targeted abilities

-Visual attention (peripheral vision as an important role)
-Speed of behavior
-Response inhibition

Figure 1.1

2.Balancing a stick with the hands (Fig. 1.2)

Task variations

-Balance the stick with one finger
-Balance the stick with the non-dominant hand
-Walk while executing the task

Targeted abilities

-Visual attention
-Speed of behavior

Figure 1.2

3.While walking, different auditory/visual signs (e.g., voice command "one") imply fast and specific psychomotor responses (e.g., "to join quickly the index and thumb fingers") (Fig. 1.3)

Figure 1.3

Task variations

- Stimulus-response number and type of combinations
-Walking in different directions during the exercise (e.g., "drawing an imaginary square in the ground by walking")
-Using balls and responding to stimuli: voice command "one" to grasp the dribbling ball; voice command "two" to change the ball quickly with another participant that have a ball with the same color; voice command "three" to change the ball quickly with another participant that had a ball with a different color…

Targeted abilities

-Speed of behavior
-Multiple-task processing

4.Two teams. Half of the participants handle a ball. The objective for those who hold a ball is to give it to someone on the other team (if the ball is lean against an "opponent" he/she must receive it); when the participant does not hold a ball, the objective is to avoid receiving one. Only walking is allowed. The "winning team" is the team that has fewer balls at end of drill (Fig. 1.4)

Figure 1.4

Task variations

-The dimension of the playing field
-The number of balls
-Three teams

Targeted abilities

-Visual attention
-Speed of behavior

5.Orienteering in an open space (Fig. 1.5)


Figure 1.5

Task variations

-Number of participants in each team
-Complexity of the course
-Participants must achieve a specific total score (attained scores are different for some of the map points); in this case, it is not necessary to travel to all orienteering points.

Targeted abilities

-Visuospatial ability
-Planning

6.Step aerobics using a map of the gymnasium. The participant should walk from step to step following the map course. During the step aerobics, a particular drill should be performed (Fig. 1.6)


Figure 1.6

Task variations

-Type of step aerobic exercises
-Map complexity

Targeted abilities

-Visuospatial ability

7.Completing a specific walking course in the gymnasium after the presentation of the associated auditory signal (the correspondence between auditory cues and walking courses was previously established) (Fig. 1.7)


Figure 1.7

Task variations

-The walking course difficulty
-Number of auditory cues-walking courses correspondence
-Two teams. At the signal, the members of each team should perform the same walking course but using opposite sequences (start point for one team is the final point for the other team). The winning team finishes first.

Targeted abilities

-Memory
-Speed of behavior

8. When the instructor moves, participants should perform the same gesture. All participants are positioned in front of the instructor (Fig. 1.8)

Figure 1.8

Task variations

- Number of gestures
-The participants should not look directly to the instructor (they should look to an object that is positioned aside or in front of the instructor)
-Some gestures of the instructor should not be imitated (no response)

Targeted abilities

-Speed of behavior
-Visual attention (peripheral reaction time is specifically targeted in some variations)
-Response inhibition

9.One participant should handle one stick in each hand. A colleague should be prepared to grab the stick immediately after it drops. He/she should look at the centre of the chest of the participant that holds the sticks. The only hand "allowed" to move is the one that will grab the dropped stick (Fig. 1.9)

Figure 1.9

Task variations

- The amplitude between the sticks

Targeted abilities

-Speed of behavior
-Visual attention (peripheral vision is specifically targeted)

10.Maintaining/batting a ball on the top of a ping-pong racquet (Fig. 1.10)

Figure 1.10

Task variations

-Establish a voice command that requires grasping the ball quickly
-Maintain the ball on the top of a ping-pong racquet while walking over Airex® balance pads
-While maintaining one ball on the top of the racquet, the participant should deliver with the other hand a ball to the the “free hand” of another participant

Targeted abilities

-Speed of behavior
-Visual attention (peripheral vision as an important role in some variations of the task)
-Multiple-task processing

11.Participants dribbling balls with different colors. When the instructor says “change” they should rapidly change the ball with another participant. When the instructor say “colors” the participants that are dribbling balls of the same color should walk to convene (the winning team is the one that gets together first) (Fig. 1.11)

Figure 1.11

Task variations

-Establish different meeting points in the gymnasium according to the ball color
-Before meeting up, the participants should complete a specific walking course in the gymnasium (different walking courses can be established according to the color of the ball)

Targeted abilities

-Speed of behavior
-Memory

12.Participants are walking in the gymnasium. The number of arcs in the ground is inferior to the number of participants. When a previous established signal is given, the participants should look for and walk to a "free" arc (Fig. 1.12)

Figure 1.12

Task variations

-While walking the participants are dribbling a ball
-Establish specific ball color-arc color correspondence
-Before meeting up the participants should complete a specific walking course in the gymnasium (different walking courses can be established for each ball color)

Targeted abilities

-Visual attention
-Speed of behavior
-Memory

13.Walking over an imaginary geometric form (a square, a circle, a "figure eight") and at the same time drawing an imaginary figure with the hands (a heart, a circle…) (Fig. 1.13)

Figure 1.13

Task variations

-Different geometric forms
-While executing this exercise, some auditory signals require specific motor responses (to stop, to unite both hands…)

Targeted abilities

-Multi-task processing
-Behavioral speed

2.Instrumentation

To support the experimental work, it was necessary to create several applications for measuring several driving-related abilities and performance. In fact, at the beginning of the project, there was little technology available for drivers' assessment. One of the main problems was the impossibility of using a driving simulator. This type of instrument is used very frequently allowing the control/manipulation of a great number of variables that are out of range in an on-road driving evaluation (furthermore, it has the advantage to guarantee the safety of the participants in the experiments). Therefore, through the work of this thesis, the conception of specific instrumentation for drivers' assessment gained a critical importance.

Four different instruments (containing several applications) were conceptualized: time-to-arrival, laboratory reaction time (RT) application, field RT application, and peripheral RT task. The first two instruments were used for laboratory evaluations; the others were employed for evaluations in on-the-road tests. It is important to point out that the use of real car driving in scientific research is not the norm but the exception: technological and safety issues frequently constrain researchers to use only laboratory tests for the assessment of driving capabilities (e.g., driving simulators). For the fieldwork of this thesis, two cars were equipped with technical instrumentation, and almost 100 tests were conducted (approximately 3000 km were covered). The driving tasks included measures of simple and choice RT, movement time, and response time, which involved the use of different parts of the visual field and included single and dual-task conditions.

In the next sections, an overview is provided regarding the major characteristics of the applications. More detailed information about the procedures used for each application is given within the methods section of the research articles included in this thesis.

2.1.Time-to-arrival

This variable was used to measure the perception of speed, an important driving ability that the standard neuropsychological tests did not evaluate. Thus, and despite some limitations of the method (see the discussion section on the article "Effects of age in Useful Field of View and Time-to-Arrival"), the TTA applications made possible to collect relevant data. The TTA applications were create with Microsoft® Visual Basic. Films of real driving situations were used in two different paradigms of investigation: target-only in motion and self-only-in motion.

Target-only in motion

This variable was investigated using a removal paradigm in which drivers saw a video projection (without sound) of an oncoming vehicle from the right direction and had to press a response button (PC) when they judged that the vehicle reached a previously established point on the road. Participants viewed the scenario filmed from a camera in a static position.

a b c

Figure 2.1. Scenes from the *target-only in motion* application. a) car is approaching, b) car was removed from the driving scene, and c) participants were instructed to press the enter button when they judged that the vehicle reached a previously established point (road sign) on the road.

Self-only in motion

An occlusion paradigm was prepared in which drivers saw a projection of a film recorded from inside a car in motion and had to press a response button (PC) when they judged that they would pass a truck that was stopped at the right side of the road (at a junction).

a b c

Figure 2.2. Scenes from the *self-only in motion* application. a) view from the inside of the car in motion, b) scenario occlusion (black screen) occurred before the car reached the arrival point, and c) participants were instructed to press a response button when they judged that they would pass a truck that was stopped at the right side of the road.

2.2.Laboratory reaction time application

For the reaction time testing, the participants were sat comfortably on a chair and grasped a steering wheel (Thrustmaster®). Accelerator and brake pedals (Thrustmaster®) were used. Real scenes were filmed in an urban context from inside a car travelling at a moderate velocity.

a b c

Figure 2.3. Scenes from the Laboratory RT application and correspondent responses

Brake reaction time

From time to time, the leading car's rear brake lights were activated (Fig. 2.3a). Participants were instructed to react as quickly as possible to that stimulus using the right foot to manage the accelerator and brake pedals. Films were projected in the wall. The foot pedal data were collected using microswitches, which were connected to a MP100 Biopac® data acquisition system that was associated with a PC. This was also the primary task used for the dual-task condition (for the secondary task, a mental calculation task was used which required participants to verbally report the result of sum of pairs of numbers)

Choice reaction time

A microswitch was attached to the steering wheel and connected to the Biopac® system, making possible the instantaneous detection of movement and respective direction. In the two-choice condition, the stimuli were: (i) the leading car rear brake lights are activated (Fig. 2.3a) and (ii) a person suddenly cuts across from the right side just in front of the participant's vehicle (Fig. 2.3b). In the first condition, the participant should brake; in the second condition, the participant should steer the wheel to the left in order to avoid the unexpected pedestrian. For the three-choice reaction time task, another stimulus was added: (iii) a person suddenly appears from the left side. In this situation, the participant should steer the wheel to the right in order to avoid the unexpected pedestrian (Fig. 2.3c). Participants were instructed to react as quickly as possible.

2.3.Field Reaction Time application

Two instrumented cars were used in the experiments: participants drove a Volkswagen Golf and a research assistant drove a Fiat Uno. In the Fiat a radio telemetry transmitter was instantly activated by the car electric circuit whenever the rear brake light was turned on; in the Volkswagen, the testing devices included a radio telemetry receiver, and movement sensors attached to the foot pedals (Fig. 2.4). Two different groups of telemetry instruments were used. In one study, industrial radio frequency remote control emitter (Cebek® TL-15) and receiver (Cebek® TL-2) were used (Figs. 2.5 and 2.6). In a second study, a more common radio transmitters/receivers (“walkie talkies”) were adapted (Figs. 2.7 and 2.8). This modification was made to allow for a more user-friendly and robust system (e.g., resistance to the car shakiness). In fact, the industrial telemetric instruments required an intervention from a technician in order to install/modify specific components (e.g., power supply and phototransistor optical switch). The technical apparatus was much easier to set up with the “walkie talkies”, and its maintenance required minimal effort.

In both radio telemetry systems the car electric circuit (12v) triggered the transmission signal (Fig. 2.9) whenever the rear brake light was turned on. All signs were detected by a MP100 Biopac® system (Fig. 2.10) interfaced with a laptop and treated with Acqnowledge® 3.7.2 software. Systems accuracy was confirmed using a wired connection from the car electric circuit to the MP100: both signals (wired and wireless - telemetry) were triggered simultaneously and entered in the MP100, which allowed for the confirmation of the telemetry system precision (Fig 2.11).

The signal of the accelerator was registered when it was initially released; the signal from the brake pedal was detected when it was initially depressed. One investigator seated in the back seat in the vehicle driven by the participant (Fig. 2.12) ensured that the design protocols were followed, namely that the sequence and time intervals between stimuli were identical for all participants and that the required distance to the leading car was maintained. He used an auricular connected to a MP3 player containing an audio recording providing the moment each stimulus should be onset. In the tasks where the stimulus included the activation of the leading car’s rear brake lights (Fig. 2.13), a radio sign was transmitted to the research assistant in order to depress the brake pedal.

Brake reaction time

Participants were instructed to brake as quickly as possible whenever the leading car’s rear brake lights were activated. Measures were collected in both single and dual-task conditions.

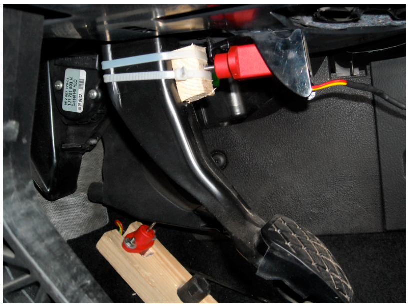


Figure 2.4. Movement sensors attached to the rear car foot pedals.

Figure 2.5. Radio telemetry system 1. Fiat Uno drove by the research assistant; telemetry transmitter is visible.

Figure 2.6. Radio telemetry system 1. Volkswagen Golf drove by the participants; telemetry receiver is visible.

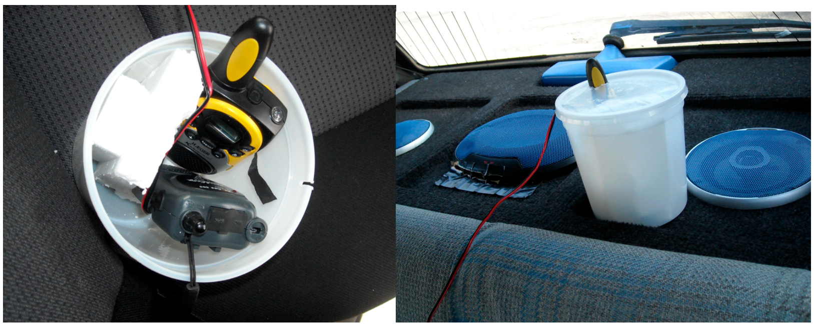


Figure 2.7. Radio telemetry system 2. Telemetry transmitters are visible.

Figure 2.8. Radio telemetry system 2. Telemetry receiver is connected to the MP100 Biopac® system.

Figure 2.9. A connection in the electric circuit of the Fiat Uno was assembled: when the brake pedal was depressed the telemetric transmitter was activated.

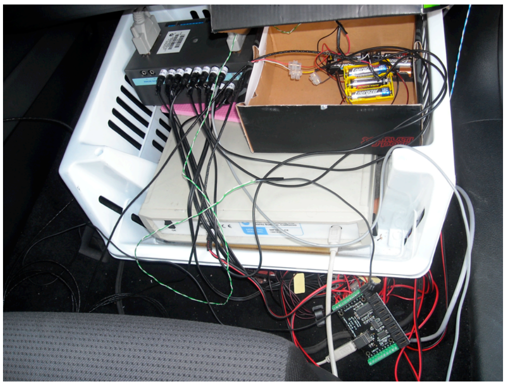


Figure 2.10. All signals were detected by a MP100 Biopac® system.

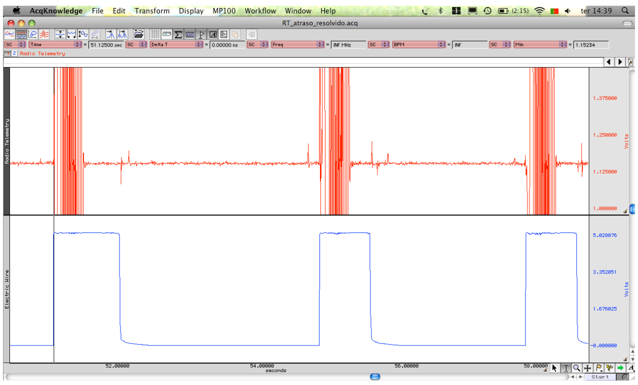


Figure 2.11. Wired and wireless signals were acquired using the Acqnowledge® 3.7.2 software to confirm the telemetry system accuracy.

Figure 2.12. Investigator seated in the back seat in the vehicle driven by the participant.

Figure 2.13. Onset of the rear brake lights of the Fiat Uno.

Figure 2.14. Experimental cars during a driving test.

Figure 2.15. Instrumentation was covered with a black cloth.

Peripheral reaction time

Six red light emitting diodes (LEDs) were positioned on the car's windshields (5 in the front and 1 in the left windshield) (Fig. 2.16). In order to cover both sides of the field of view, the LEDs were placed approximately at 10º, 20º and 30º left (3 LEDs) and right (3 LEDs) of the centre of the sight line of the driver and approximately 8º elevated above the car console. The LEDs have a light intensity of 10.0 cd. The participants reacted by depressing a microswitch with their left thumb that was attached to the left side of the steering wheel (Fig. 2.16). One LED at a time was illuminated during 2s (fewer time if the microswitch was depressed). One investigator seated in the back seat in the vehicle driven by the participant (Fig. 2.13) ensured that the design protocols were followed, namely that the sequence and time intervals between stimuli were identical for all participants and that the required distance to the leading car was maintained. He used an auricular connected to a MP3 player containing an audio recording providing the moment each stimulus should be onset. The LEDs were controlled using a laptop and a Phidget® interface kit (Fig. 2.17).

Figure 2.16. Six red LEDs were positioned on the car's windshields (5 in the front and 1 in the left windshield).

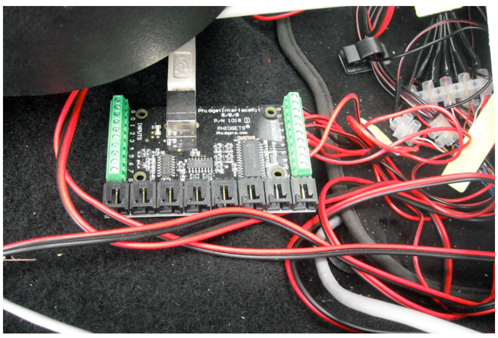


Figure 2.17. A Phidget® interface kit was used to control the 6 LEDs.

Choice reaction time

This test required both the telemetric system and the Peripheral RT instrumentation. The participants were instructed to follow the leading car and to react as quickly as possible to the stimuli: (i) the leading car rear brake lights were activated and (ii) one of two LEDs placed in the front windshield (20º left and right) were activated (Fig. 2.18). In the first condition, the participant should brake; in the second condition, the participant should depress the microswitch attached to the steering wheel with their left thumb. The utilization of two LEDs instead of one intended to target both sides of the visual field and to avoid any posture adjustments of the driver to position the LEDs in a more central region of his/her visual field. Once more, the investigator (sequence and time intervals between stimuli) seated in the back seat in the vehicle driven by the participant ensured that the design protocols were followed.

Figure 2.18. Stimuli used in the Field Choice Reaction Time test.

Figure 2.19. Driving tests were conducted on public roads with low traffic density.

REFERENCES

Ball, K., Wadley, V., Vance, D., & Edwards, J. (2004). Cognitive skills: training, maintenance, and daily usage. In C. Speilberg (Ed.), *Encyclopedia of Applied Psychology* (pp. 387-392): Elsevier Science.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: further evidence for cognitive plasticity in attentional control in late adulthood. *Exp Aging Res, 34*(3), 188-219.

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci, 14*(2), 125-130.

Fabre, C., Chamari, K., Mucci, P., Masse-Biron, J., & Prefaut, C. (2002). Improvement of cognitive function by mental and/or individualized aerobic training in healthy elderly subjects. *Int J Sports Med, 23*(6), 415-421.

Hultsch, D. F., Hertzog, C., Small, B. J., & Dixon, R. A. (1999). Use it or lose it: engaged lifestyle as a buffer of cognitive decline in aging? *Psychol Aging, 14*(2), 245-263.

Kramer, A. F., Colcombe, S. J., McAuley, E., Eriksen, K. I., Scalf, P., Jerome, G. J., et al. (2003). Enhancing brain and cognitive function of older adults through fitness training. *J Mol Neurosci, 20*(3), 213-221.

Magill, R. (2003). *Motor Learning and control, concepts and applications* (Seventh ed.). New York: McGraw-Hill.

Matos, R., & Godinho, M. (2009). Useful field of vision and peripheral reaction time in novice drivers: transfer to a real driving situation after a perceptual-motor training program. *Advances in Transportation Studies: An International Journal., 19*, 77-84.

Pesce, C., Cereatti, L., Casella, R., Baldari, C., & Capranica, L. (2007). Preservation of visual attention in older expert orienteers at rest and under physical effort. *J Sport Exerc Psychol, 29*(1), 78-99.

Roth, D. L., Goode, K. T., Clay, O. J., & Ball, K. K. (2003). Association of physical activity and visual attention in older adults. *J Aging Health, 15*(3), 534-547.

Smiley-Oyen, A. L., Lowry, K. A., Francois, S. J., Kohut, M. L., & Ekkekakis, P. (2008). Exercise, fitness, and neurocognitive function in older adults: the "selective improvement" and "cardiovascular fitness" hypotheses. *Ann Behav Med, 36*(3), 280-291.

CHAPTER III

Effects of aging and physical activity on driving-related abilities

Article 2. **Associations between physical activity and driving-related cognitive abilities in older drivers: an exploratory study**

Article 3. **Effects of age in Useful Field of View and Time-to-Arrival**

Associations between physical activity and driving-related cognitive abilities in older drivers: an exploratory study

José Marmeleira, Inês Ferreira, Filipe Melo, Mário Godinho

Abstract

Physical Activity (PA) positively influences several abilities that have been associated with driving performance in older adults. However, few studies have explored the potential link between PA and driving. The purpose of this study was to examine the associations between PA and driving-related cognitive abilities in older drivers. Thirty-eight drivers (16 females and 22 males) of ages between 61 and 81 years (70.2 ± 5.0 years) responded to the International PA Questionnaire and were assessed using a battery of neuropsychological tests that included measures of visual attention, executive functioning, mental status, visuospatial ability and memory. A higher level of PA was correlated with better scores on tests of visual processing speed (r=-0.34, *p*=0.047) and divided visual attention (r=-0.40, *p*=0.003). Higher levels of PA were associated with a better composite score for visual attention (r=-0.48, *p*=0.004) and almost significantly correlated with a better composite score for executive functioning (r=-0.33, *p*=0.053). These findings support the hypothesis that PA is associated with the preservation of specific driving-related cognitive abilities in older drivers. The potential benefit of PA on driving in later life is discussed.

Key words: Driving, aging, physical activity, cognitive functioning

---

Submitted

INTRODUCTION

Aging is associated with a decline in several cognitive skills and brain functions (Bixby, et al., 2007; Spirduso, Francis, & MacRae, 2005), which can result in driving difficulties. It was reported that older drivers have a high crash rate per distance travelled (Guerrier, Manivannan, & Nair, 1999; Lyman, Ferguson, Braver, & Williams, 2002; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998) and an increased risk of injury or death in a traffic crash (Li, Braver, & Chen, 2003; McGwin, Sims, Pulley, & Roseman, 2000).

Physical activity (PA) has a positive effect on diverse cognitive abilities (Bixby, et al., 2007; Dustman, Emmerson, & Schearer, 1994; Kramer, et al., 2002) that have been associated with driving performance and safety among older adults. For instance, older people with a good physical fitness level show greater efficiency in information processing (Etnier, et al., 1997; Kramer, et al., 2002), enhancement of attention capacity (Hawkins, Kramer, & Capaldi, 1992; Roth, Goode, Clay, & Ball, 2003), better performance on tasks that require visuospatial processing (Shay & Roth, 1992), and benefits for executive-control processes (Colcombe & Kramer, 2003). The effects of PA on cognition seem to be more accentuated in tasks that request greater attention resources (Chodzko-Zajko & Moore, 1994; Etnier, et al., 1997; van Boxtel, et al., 1997), as is the case of driving (Hoffman, McDowd, Atchley, & Dubinsky, 2005).

Several mechanisms that underlie the relationship between PA and cognition have been examined. For example, it has been considered that the participation in exercise programs may induce brain-vascular and neuro-chemistry benefits that allow the preservation of cognitive functioning in the elderly (Chodzko-Zajko, 1991; Dustman, et al., 1994). Recently, significant increases in brain volume in both gray and white matter regions were found as a function of fitness training for older adults, suggesting a strong biological basis for the role of aerobic fitness in maintaining and enhancing central nervous system health and cognitive functioning (Colcombe, et al., 2006). The frontal system, a region that mediates executive function, seems to be the primary locus in which aging-related cognitive deficits are found and is also the area where physical fitness appears to exert its greatest influence (Bixby, et al., 2007; Colcombe & Kramer, 2003; Kramer, et al., 2002).

Even in normal aging there is a decline in many cognitive abilities, leading to the emergence of driving difficulties. It is known that PA influences positively several cognitive abilities considered essential for driving. However, to the best of our knowledge, no study has examined the association between PA and driving-related cognitive abilities in a sample of older drivers. Therefore, the purpose of this study is to determine the association between self-reported PA in older drivers and scores on a battery of neuropsychological tests.

METHODS

Participants

Thirty-eight active drivers (16 females and 22 males) aged between 61 and 81 years (70.2 ± 5.0 years) participated in this study. The participants were volunteers recruited in the region of Lisbon, Portugal, from two senior universities and a health program for older adults. Participants were contacted by phone or personally. The inclusion criteria for participants were: aged 60 years or more; live independently in the community; possess a valid driving license; 20/40 or greater corrected binocular vision measured with a Snellen Chart; normal cognitive status on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975); no severe chronic illness; no alcohol and drug dependence; no sensorial, motor or language deficit that could interfere on cognitive test results. All participants drive ≥ 2 days per week, and had a driver's license for over 10 years; 26% completed elementary school, 32% completed middle and high school, and 42% were university graduates.

Evaluations were performed individually. All testing took place in a single session lasting about 2 hours. Prior to participation, the study was explained and written informed consent was obtained from each participant. Participants were assured that the study results were confidential and had no bearing on their driving licence. To check inclusion criteria, a questionnaire was designed to gather information on demographic variables (age, gender, place of residence, education level, etc.), functional impairments and medical conditions (e.g., chronic conditions, alcohol and drug dependence, medication). The study protocol included a battery of visual, physical and cognitive tests, and a survey on driving habits and difficulties. All cognitive tests were selected from previous research showing a relationship with driving measures (crash involvement or on-road driving performance): UFOV® (Ball

& Owsley, 1993), Tower of London (TOL; Shallice, 1982), Trail Making Test (TMT; Reitan, 1958), Rey-Osterrieth Complex Figure Test (CFT-copy & CFT-recall; Rey, 1991), and Block Design subtest from the WAIS-III (BD; Wechsler, 1997).

Physical activity by self-report

The International PA Questionnaire-Short Form (IPAQ) is a 7-day recall measure of PA where the volume of PA is converted to Metabolic Equivalents (MET min week^{-1}). No official Portuguese version of IPAQ was available. However, the version used in this study was the same as in the 12-country reliability and validity study (www.ipaq.ki.se) (Craig, et al., 2003).

The questionnaire collects information on time (i.e. number of sessions and average time per session) spent walking in moderate and vigorous PA. Information on sitting time is also collected. Questions regarding participation in moderate and vigorous activity were supplemented by specific examples of activities commonly performed. Data from the questionnaire were summed within each item (i.e. vigorous intensity, moderate intensity, walking) to estimate the total amount of time spent in PA per week. To calculate the MET min week^{-1} we used the international recommendations (www.ipak.ki.se): (i) the total time in min per week for each category of PA was multiplied by the correspondent MET estimates of IPAQ (vigorous intensity, 8 METs; moderate-intensity, 4 METs; and walking, 3.3 METs); (ii) all values were summed.

Useful field of view

The three subtests of UFOV® (PC version) were administered to measure speed of visual processing (subtest 1), divided attention (subtest 2), and selective attention (subtest 3). The first subtest requires the identification of a target (silhouette of a car or truck) presented in a central fixation box. The second subtest measures divided attention and involve the identification of the central target along with the localization of a simultaneous peripheral target (silhouette of a car or truck). The third subtest consists of these same two tasks, but also includes visual distracters (triangles of the same size and luminance as the targets) that fill the rest of the visual display. Data were collected in time (ms). Several studies support that impairments in the useful field of view are associated with higher crash risk (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Owsley, Ball, Sloane, Roenker, & Bruni, 1991; Sims, McGwin, Allman, Ball, & Owsley, 2000) or poorer on-road driving performance (Whelihan, DiCarlo, & Paul, 2005).

Trail Making Test

The participant uses a pencil to sequentially connect numbers in ascending order (TMT-A), or a mix of numbers and letters that are distributed across a page in an alternating and ascending order (i.e., 1-A-2-B, and so on) (TMT-B). They are instructed to do the task as quickly as possible and without lifting the pencil from the paper. The time in seconds to finish each part is recorded. This test is used to assess speed of visual search, divided attention, sequencing with a motor component, and mental flexibility (Strauss, Sherman, & Spreen, 2006). In particular, TMT-B is more sensitive to executive functions (Lezak, Howieson, & Loring, 2004). Several studies on older drivers have demonstrated a correlation between TMT and crash involvement (e.g., Lundberg, Hakamies-Blomqvist, Almkvist, & Johansson, 2003) or on-road driving performance (e.g., Kantor, Mauger, Richardson, & Unroe, 2004).

Tower of London

Participants are asked to preplan mentally a sequence of moves to match a start set of 3 colored balls to a goal, and then to execute the moves one by one. The principal measures employed were: the planning time (time between the beginning of the task and the first movement), the execution time (total time minus planning time), and the number of trials performed (the minimum was 12 corresponding to the number of problems presented). This test is used to assess executive functions, in particular, planning ability (Lezak, et al., 2004). The Tower of London performance was previously associated with elderly drivers having a history of accidents (Daigneault, Joly, & Frigon, 2002).

Rey-Osterrieth Complex Figure Test

Participants are required to copy a complex geometric figure (copy task) before recalling it from memory some 3 minutes later (recall task). The quantitative correction is based on time (seconds), number and localization of the elements. Copy task provides a reliable index of visuoconstructional ability, while recall task measures visual memory (Lezak, et al., 2004). In older drivers, both tasks were associated with crash involvement (Lundberg, et al., 2003).

Block Design

Participants are asked to replicate a maximum set of 14 printed two dimensional geometric patterns using two-color cubes. Four designs must be completed within 30 seconds, five within 60 seconds, and five within 120 seconds. A design can be failed because of faulty construction or exceeding the time limit. This visuospatial test is a measure of visuoconstructional ability and was associated with crash involvement in older drivers (Lundberg, Hakamies-Blomqvist, Almkvist, & Johansson, 1998; Lundberg, et al., 2003).

Statistical Analysis

Partial correlations were conducted to assess the relationships between PA and cognitive performance. A composite score was calculated for each cognitive ability by summing the standardized value (z scores) of the respective cognitive tests; a general cognitive score was computed by summing the composite scores of all cognitive abilities. Significance was set at $p < 0.05$ for all tests. Statistical analysis was carried out using SPSS 17.0 for Windows (SPSS, Chicago, IL).

RESULTS

Most participants achieve, at least, a moderate level of weekly PA (Table 1) as measured by the IPAQ, and 27 participants (71% of the total sample) practice regularly some type of exercise program (e.g., dancing, swimming, resistance training).

Partial correlations between the amount of weekly PA and cognitive test scores are presented in Tables 2, 3 and 4. Higher amount of PA was associated with better scores in visual processing speed ($r=-0.34$, $p=0.047$) and divided visual attention (r=-0.49, p=0.003). The association between the amount of PA and the time to complete the TMT-A came close of reaching statistical significance (r=-0.32, p=0.057). In executive functioning, the associations between planning time on the TOL and PA also fell short of reaching statistical significance (r=-0.30, p=0.082).

The results for each cognitive ability (Table 5) showed that higher levels of PA are significantly associated with better scores on visual attention (r=-0.48, p=0.004) and almost significantly associated with executive functioning (r=-0.33, p=0.053). Finally, the correlation between levels of PA and general cognitive performance (r=-0.28, p=0.094) fell short of reaching statistical significance.

Table 1. Participants by level of PA according to IPAQ

Level of PA	n	(%)
Low	4	10.5
Moderate	20	52.6
High	14	36.9

Table 2. Correlation matrix for PA and measurements of visual attention

	M	SD	1.	2.	3.	4.
1.MET-minute week^{-1}	1727.5	1117.2	-			
2.Processing Speed (ms)	40.5	81.7	-0.34*	-		
3.Divided Attention (ms)	171.0	134.4	-0.49**	0.38*	-	
4.Selective Attention (ms)	353.4	119.5	-0.18	0.02	0.50**	-
5.TMT-A (s)	49.8	17.8	-0.32	0.27	0.42*	0.36*

Note. *p<0.05, **p<0.01. Partial correlations controlling for visual acuity, age and education. For all cognitive tests lower scores indicate greater performance.

Table 3. Correlation matrix for PA and measurements of executive functioning

	M	SD	1.	2.	3.	4.
1.MET-minute week^{-1}	1727.5	1117.2	-			
2.TMT-B (s)	106.4	53.4	-0.25	-		
3.TOL total trials (N.)	19.1	3.3	-0.18	0.49**	-	
4.TOL planning time (s)	7.4	4.5	-0.30	0.11	-0.18	-
5.TOL execution time (s)	6.9	2.1	-0.13	0.56**	0.31	0.19

Note. **p<0.01. Partial correlations controlling for age and education. For all cognitive tests lower scores indicate greater performance.

Table 4.
Correlation matrix for PA and measurements of visuospatial constructional ability and memory

	M	SD	1.	2.	3.
1.MET-minute week^{-1}	1727.5	1117.2	-		
2.CFT copy score	31.4	7.01	-0.04	-	
3.CFT recall score	10.9	7.6	-0.08	0.52**	-
4.Block Design	24.8	6.3	0.10	0.37*	0.38*

Note. **p*<0.05, ***p*<0.01. Partial correlations controlling for age and education.

Table 5. Correlations between PA and cognitive composite scores

	Visual Attention	Exec. Functioning	Visuospatial and Memory	Cognitive Composite
MET-minute week^{-1}	-0.48**	-0.33	-0.02	-0.28

Note. ***p*<0.01. Partial correlations controlling for age and education; visual acuity were also controlled for the visual attention composite. Composite scores were coded where appropriate so that negative numbers reflect better cognitive performance.

DISCUSSION

This study intends to contribute to bridge the gap between the practice of PA and driving performance in older adults. It demonstrated that higher levels of PA are moderately associated with better visual attention in a sample of older drivers. Moreover, despite the lack of statistical significance, there was a clear tendency for better executive functioning and general cognitive performance in drivers with higher levels of PA.

The results are in line with a growing body of evidence that PA could have an important role on the attenuation of age-related declines in brain function and health (e.g., Etnier, 2008; Kramer, Colcombe, McAuley, Scalf, & Erickson, 2005). This could be relevant in the context of driving because cognitive performance may be the strongest predictor of subsequent driving limitations (Marcotte & Scott, 2009; Vance, et al., 2006).

Previous investigations have also reported that PA can improve visual attention in older adults. It was shown that aerobic exercise (10 weeks of aquatic training) induced a beneficial influence on attention in older adults during dual-task processing (Hawkins, et al., 1992), and that individuals who regularly engaged in PA had significantly better UFOV® scores than less active individuals (Roth, et al., 2003). Furthermore, it was demonstrated that elderly individuals with expertise in orienteering activities have developed attentional skills that outweigh the expected age-related changes (Pesce, Cereatti, Casella, Baldari, & Capranica, 2007).

Lower results in the divided attention test of the UFOV® have been recurrently associated with driving outcomes (e.g., crashes and on-road drive tests performance) among older drivers (e.g., Anstey, Wood, Lord, & Walker, 2005; Ball, et al., 2006). However, the importance of preserving visual attention skills is not circumscribed to driving; it might lead to a number of benefits including greater independence and a higher quality of life (Roth, et al., 2003). For instance, better performance in the UFOV® has been found to be predictive of older adults' ability to quickly and accurately perform instrumental activities of daily living (Owsley, Sloane, McGwin, & Ball, 2002).

A low association was found between PA and executive functioning. Nevertheless, this association fell short of reaching statistical significance. It seems reasonable to expect that significant associations might be found between those two variables if a larger sample size and a more equilibrate range of PA habits has been contemplated. In fact, previous results suggest that PA might be capable of influence positively executive functioning, which encompasses cognitive abilities like inhibition, planning, mental flexibility, and set-shifting. Colcombe and Kramer (2003), in a meta-analytic review of fitness intervention studies, found a clear and significant effect of aerobic fitness training in the cognitive function of older adults, and these effects were particularly evident in tasks that involved executive functions. In the driving-related literature, it has been pointed that if the types of crashes in which older adults are involved often occur in complex traffic situations such as intersections (Mayhew, Simpson, & Ferguson, 2006; McGwin & Brown, 1999), it is reasonable to hypothesize that difficulties occur at the level of executive function (i.e., the planning and decision-making part of the driving task) (Anstey, et al., 2005). It was reported that poor planning ability is independently associated with driving difficulties (Ferreira, Marmeleira, Godinho, & Simões, 2007) and that drivers who had accidents during the previous 5 years performed poorly on tasks of executive functioning (Daigneault, et al., 2002).

Significant differences between high- and low-fit older adults were previously found on tasks that require visuospatial processing (Shay & Roth, 1992). The results in the present study did not support such a relationship, since PA was not associated with visuospatial processing and memory. In their frequently cited meta-analysis, Colcombe and Kramer (2003) after defined a visuospatial category that includes tasks that tapped the participants' ability to transform or remember visual and spatial information, have concluded that it did not benefit significantly from better fitness condition.

Regardless of the limited variability observed in the PA habits of the participants (only 11% were classified as having low amounts of PA per week), it is noteworthy that a positive association was found between PA and some measures of cognitive functioning. Most likely, the positive "PA profile" of the individuals that participated in this study is not representative of the general community-dwelling older adults. Thus, it is expectable that stronger associations have been observed in a sample of individuals with more heterogeneous PA habits.

The present study has some limitations that future research needs to address. The cross-sectional nature of the study complicates the interpretation of results, making difficult to establish cause-effect relations: regular PA may promote adaptations that preserve/enhance cognitive abilities, but it is also possible that those with higher scores on cognitive abilities choose to participate in PA more frequently. Also, a relatively small sample of subjects participated and, as pointed before, they possess relatively homogeneous PA habits. Finally, despite the use of various measures of cognitive functioning that have been related to driving, actual driving was not evaluated.

In summary, this research seeks to bridge the gap between the research on the effects of PA in cognitive functioning and the research about cognitive factors associated with driving performance in older adults. Higher levels of PA were significantly correlated with better performance in visual attention and almost significantly correlated with better results on executive functioning. Thus, evidence was found that PA is associated with the preservation of specific driving-related cognitive abilities in older drivers. Subsequent investigations would be justified to determine whether these relationships reflect cause-effect mechanisms.

REFERENCES

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clin Psychol Rev, 25*(1), 45-65.

Ball, K., & Owsley, C. (1993). The useful field of view test: a new technique for evaluating age-related declines in visual function. *J Am Optom Assoc, 64*(1), 71-79.

Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Invest Ophthalmol Vis Sci, 34*(11), 3110-3123.

Ball, K. K., Roenker, D. L., Wadley, V. G., Edwards, J. D., Roth, D. L., McGwin, G., Jr., et al. (2006). Can high-risk older drivers be identified through performance-based measures in a Department of Motor Vehicles setting? *J Am Geriatr Soc, 54*(1), 77-84.

Bixby, W. R., Spalding, T. W., Haufler, A. J., Deeny, S. P., Mahlow, P. T., Zimmerman, J. B., et al. (2007). The unique relation of physical activity to executive function in older men and women. *Med Sci Sports Exerc, 39*(8), 1408-1416.

Chodzko-Zajko, W. J. (1991). Physical fitness, cognitive performance, and aging. *Med Sci Sports Exerc, 23*(7), 868-872.

Chodzko-Zajko, W. J., & Moore, K. A. (1994). Physical fitness and cognitive functioning in aging. *Exerc Sport Sci Rev, 22*, 195-220.

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci, 14*(2), 125-130.

Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R., McAuley, E., et al. (2006). Aerobic exercise training increases brain volume in aging humans. *J Gerontol A Biol Sci Med Sci, 61*(11), 1166-1170.

Craig, C. L., Marshall, A. L., Sjostrom, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., et al. (2003). International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc, 35*(8), 1381-1395.

Daigneault, G., Joly, P., & Frigon, J. Y. (2002). Executive functions in the evaluation of accident risk of older drivers. *J Clin Exp Neuropsychol, 24*(2), 221-238.

Dustman, R., Emmerson, R., & Schearer, D. (1994). Physical Activity, age, and cognitive neuropsychological function. *J Aging Phys Act, 2*, 143-181.

Etnier, J. (2008). Interrelationships of exercise, mediator variables, and cognition. In W. W. Spirduso, L. W. Poon & Chodzko-Zajko (Eds.), *Exercise and its mediating effects on cognition* (pp. 13-32). Champaign, IL: Human Kinetics.

Etnier, J., Salazar, W., Landers, D., Petruzzello, S., Han, M., & Novell, P. (1997). The influence of physical fitness and exercise upon cognitive functioning: a meta analysis. *J Sport Exerc Psychol, 19*(3), 249-277.

Ferreira, I., Marmeleira, J., Godinho, M., & Simões, M. (2007). *Cognitive factors and gender related to self-reported difficulties in older drivers.* Paper presented at the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Stevenson, Washington.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res, 12*(3), 189-198.

Guerrier, J. H., Manivannan, P., & Nair, S. N. (1999). The role of working memory, field dependence, visual search, and reaction time in the left turn performance of older female drivers. *Appl Ergon, 30*(2), 109-119.

Hawkins, H. L., Kramer, A. F., & Capaldi, D. (1992). Aging, exercise, and attention. *Psychol Aging, 7*(4), 643-653.

Hoffman, L., McDowd, J. M., Atchley, P., & Dubinsky, R. (2005). The role of visual attention in predicting driving impairment in older adults. *Psychol Aging, 20*(4), 610-622.

Kantor, B., Mauger, L., Richardson, V., & Unroe, K. (2004). An analysis of an older driver evaluation program. *J Am Geriatr Soc, 52*, 1326-1330.

Kramer, A. F., Colcombe, S., Erickson, K., Belopolsky, A., McAuley, E., Cohen, N. J., et al. (2002). Effects of aerobic fitness training on human cortical function: a proposal. *J Mol Neurosci, 19*(1-2), 227-231.

Kramer, A. F., Colcombe, S. J., McAuley, E., Scalf, P. E., & Erickson, K. I. (2005). Fitness, aging and neurocognitive function. *Neurobiol Aging, 26 Suppl 1*, 124-127.

Lezak, M., Howieson, D., & Loring, D. (2004). *Neuropsychological Assessment* (4rd ed.). New York: Oxford University Press.

Li, G., Braver, E. R., & Chen, L. H. (2003). Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. *Accid Anal Prev, 35*(2), 227-235.

Lundberg, C., Hakamies-Blomqvist, L., Almkvist, O., & Johansson, K. (1998). Impairments of some cognitive functions are common in crash-involved older drivers. *Accid Anal Prev, 30*(3), 371-377.

Lundberg, C., Hakamies-Blomqvist, L., Almkvist, O., & Johansson, K. (2003). License suspension revisited: A 3-year follow-up study of older drivers. *J Appl Gerontol, 22*(4), 427-444.

Lyman, S., Ferguson, S. A., Braver, E. R., & Williams, A. F. (2002). Older driver involvements in police reported crashes and fatal crashes: trends and projections. *Inj Prev, 8*(2), 116-120.

Marcotte, T., & Scott, J. (2009). Neuropsychological performance and the assessment of driving behaviour. In I. Grant & K. Adams (Eds.), *Neuropsychological assessment of neuropsychiatric and neuromedical disorders* (pp. 652-687). New York: Oxford University Press.

Mayhew, D. R., Simpson, H. M., & Ferguson, S. A. (2006). Collisions involving senior drivers: high-risk conditions and locations. *Traffic Inj Prev, 7*(2), 117-124.

McGwin, G., Jr., & Brown, D. B. (1999). Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accid Anal Prev, 31*(3), 181-198.

McGwin, G., Jr., Sims, R. V., Pulley, L., & Roseman, J. M. (2000). Relations among chronic medical conditions, medications, and automobile crashes in the elderly: a population-based case-control study. *Am J Epidemiol, 152*(5), 424-431.

Owsley, C., Ball, K., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1991). Visual/cognitive correlates of vehicle accidents in older drivers. *Psychol Aging, 6*(3), 403-415.

Owsley, C., Sloane, M., McGwin, G., Jr., & Ball, K. (2002). Timed instrumental activities of daily living tasks: relationship to cognitive function and everyday performance assessments in older adults. *Gerontology, 48*(4), 254-265.

Pesce, C., Cereatti, L., Casella, R., Baldari, C., & Capranica, L. (2007). Preservation of visual attention in older expert orienteers at rest and under physical effort. *J Sport Exerc Psychol, 29*(1), 78-99.

Preusser, D. F., Williams, A. F., Ferguson, S. A., Ulmer, R. G., & Weinstein, H. B. (1998). Fatal crash risk for older drivers at intersections. *Accid Anal Prev, 30*(2), 151-159.

Reitan, R. (1958). Validity of the Trail Making Test as an indicator of organic brain damage. *Percept Mot Skills, 8*, 271-276.

Rey, A. (1991). L'examen psychologique dans les cas d'encéphalopathie traumatique. *Archives de Psychologie, 28*, 286-340.

Roth, D. L., Goode, K. T., Clay, O. J., & Ball, K. K. (2003). Association of physical activity and visual attention in older adults. *J Aging Health, 15*(3), 534-547.

Shallice, T. (1982). Specific impairments of planning. *Philosophical transcripts of the Royal Society of London, 298*, 199-290.

Shay, K. A., & Roth, D. L. (1992). Association between aerobic fitness and visuospatial performance in healthy older adults. *Psychol Aging, 7*(1), 15-24.

Sims, R. V., McGwin, G., Jr., Allman, R. M., Ball, K., & Owsley, C. (2000). Exploratory study of incident vehicle crashes among older drivers. *J Gerontol A Biol Sci Med Sci, 55*(1), M22-27.

Spirduso, W. W., Francis, K. L., & MacRae, P. G. (2005). *Physical Dimensions of Aging-2nd Edition*. Champaign, IL: Human Kinetics.

Strauss, A., Sherman, E., & Spreen, O. (2006). *Compendium of neuropsychological tests: Administration, norms, and commentary* (3rd ed.). New York: Oxford University Press.

van Boxtel, M. P., Paas, F. G., Houx, P. J., Adam, J. J., Teeken, J. C., & Jolles, J. (1997). Aerobic capacity and cognitive performance in a cross-sectional aging study. *Med Sci Sports Exerc, 29*(10), 1357-1365.

Vance, D. E., Roenker, D. L., Cissell, G. M., Edwards, J. D., Wadley, V. G., & Ball, K. K. (2006). Predictors of driving exposure and avoidance in a field study of older drivers from the state of Maryland. *Accid Anal Prev, 38*(4), 823-831.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale* (Third ed.). San Antonio, TX: The Psychological Corporation.

Whelihan, W. M., DiCarlo, M. A., & Paul, R. H. (2005). The relationship of neuropsychological functioning to driving competence in older persons with early cognitive decline. *Arch Clin Neuropsychol, 20*(2), 217-228.

Effects of age in Useful Field of View and Time-to-Arrival

José Marmeleira, Mário Godinho, Jorge Malarranha, Orlando Fernandes

Abstract

The main aim of this study was to investigate the effects of age on the Useful Field of View (UFOV) and in the estimation of Time to Arrival (TTA) among a group of drivers. Ninety-six male and female participated in this research: 32 young (18-30 years), 32 middle-aged (38-50 years) and 32 older (60-75 years) drivers. In the Useful Field of View test (UFOV®), older drivers had significant poorer performances in divided and selective attention than the other age groups. Furthermore, some nonlinear variations occurred, revealing a much more evident decrease in visual attention performance from the middle-aged to the older group than from the younger to the middle-aged group. For TTA, a single difference was found between the age groups: TTA estimations of older drivers were more variable in judging a vehicle approaching at 50 km/h. The accuracy of TTA estimations increased when the approaching vehicle travelled at higher speeds. Although not statistically significant, a U-shape relationship was observed between age and response bias on the TTA estimations. We conclude that visual attention is much more sensitive to the effects of age than speed perception, and therefore, intervention programs should be designed to enhance the UFOV in older drivers. The effectiveness of the TTA paradigm for driving behavior analysis is discussed.

Keywords: Aging, driving, time-to-arrival, useful-field-of-view

Advances in Transportation Studies: An International Journal (2009), 17: 29-38.

INTRODUCTION

Visual attention and speed perception are important abilities for safe driving across the lifespan (Anstey, Wood, Lord, & Walker, 2005; Hesketh & Godley, 2002). Nevertheless, many studies that investigate the effects of age on driving capability frequently focus on older adults or compare them with young adults, omitting the middle-aged drivers; this makes it difficult to understand the evolution of abilities through the aging process.

Visual function tests alone have little sensitivity in identifying risky drivers (Owsley, et al., 1998). The concept of useful field of view (UFOV) was first introduced by Sanders (1970) who used the term “functional visual field” to indicate the visual field area over which information can be acquired in a brief glance without eye or head movements. Subsequently, it has come to be most widely associated with a specific computer-based test, the Useful Field of View test (UFOV®) (Ball & Owsley, 1993). The UFOV® combines the evaluation of the visual processing speed, selective and divided visual attention, and has been identified as a valid and reliable index of driving performance and safety in older adults (Anstey, et al., 2005; Clay, 2005; Sims, McGwin, Allman, Ball, & Owsley, 2000). The performance in UFOV® relies on higher-order cognitive abilities as well as visual sensory function (Owsley, 1995).

Research on older drivers has shown that impairment in UFOV® is associated with crash involvement (Ball, et al., 2006; Owsley, et al., 1998) or on-road driving performance (Whelihan, DiCarlo, & Paul, 2005). The UFOV® fills a void because is a better predictor of vision problems in everyday life than standard visual field assessments with perimetry, which detect sensory losses across the visual field (Edwards, et al., 2006). The UFOV® performance has been found to also be predictive of older adults’ ability to perform instrumental activities of daily living (Owsley, Sloane, McGwin, & Ball, 2002).

Speed perception has also been identified as an important ability in driving (Hesketh & Godley, 2002; Owsley, et al., 1998; Raghuram & Lakshminarayanan, 2006; Staplin & Lyles, 1992). Different labels have been used to represent the ability to estimate when a moving object will reach a second object or the observer in space. The general area is known as Time-to-Contact (Hancock & Manser, 1998; Manser & Hancock, 1996). Nevertheless, several terms have been employed to describe the same phenomenon: Arrival Time (Caird & Hancock, 1994), Time-to-Arrival (Caird & Hancock, 1994; Marmeleira, Ferreira, Godinho, & Fernandes, 2007; Schiff & Oldak, 1990), and Time-to-Collision (Cavallo & Laurent, 1988). Despite some methodological differences, research in this domain aim to study the visual perception of approaching vehicles (with a stationary or in-motion observer). Time-to-Contact estimation probably involves the local transformation of optical information through changes in the size of the image on the retina (Caird & Hancock, 1994; Hesketh & Godley, 2002; Manser & Hancock, 1996). Lee (1976) originally proposed that an object's time to arrival can be obtained from the ratio of the object's image size to the rate of change of size and gave this ratio the name *tau*. However, this optic variable does not allow for accounting of the time-to-arrival judgments in various situations (e.g., Horswill, Helman, Ardiles, & Wann, 2005; Tresilian, 1994) and the debate about the information that accounts for the Time-to-Contact is still open (please see Hancock & Manser, 1997; Tresilian, 1999).

In the present study the term Time-to-Arrival (TTA) is used to describe a situation where a stationary observer sees a vehicle approaching in an indirect collision course. In this case, if the approaching vehicle had not disappeared from the scene, it would have passed just in front of the observer. This situation intends to simulate what happens in real conditions, for example when a driver who is expecting to enter the main road at an intersection has to estimate when other vehicles will reach his position in space. Correctly perceiving the speed and hence the distance and "time away" of an approaching vehicle is a very important skill in maneuvers where one has to turn across oncoming traffic (Hesketh & Godley, 2002; McGwin & Brown, 1999; Skaar, Rizzo, & Stierman, 2003). Related to this, a high proportion of older drivers accidents occur in intersections when entering the traffic or crossing a main road (Mayhew, Simpson, & Ferguson, 2006). A deficit in the perception of the speed of oncoming vehicles could hinder the adequate decision in those manoeuvres.

In our view, the investigation on the evolution of driving-related abilities across the lifespan could provide important information on driver's behavior and difficulties. The present research intends to examine the age effects on two of these abilities: visual attention and speed perception.

METHODS

Participants

Ninety-six male and female active drivers participated in this study. The sample description is presented in Table 1.

Table 1. Sample characteristics.

Age Group	Age[a] (M ± SD)	n	Gender	Age[a] amplitude
Young	23.2 ± 2.4	32	15 F, 17 M	18 - 30
Middle-aged	43.7 ± 3.3	32	14 F, 18 M	38 - 50
Older	68.8 ± 4.1	32	14 F, 18 M	60 - 75

Note. [a]Years-old

The participants were voluntary recruited in the regions of Lisbon and Évora, Portugal, from various Universities (including Senior Universities) and from a Military School. Participants were contacted by phone or personally; 10% completed elementary school, 57% completed middle and high school, and 33% were university graduates. All participants currently drive (≥ 2 days a week). Young drivers had 4.3 years (±2.4) of driving experience, middle-aged 19.8 years (±6.0) and old drivers 39.3 years (±12.1).

Procedures

The evaluations were performed individually. All testing took place in a single session lasting 40 min. A questionnaire was applied to assemble information about the driving habits. All participants had at least 20/40 binocular vision measured with a Snellen Chart. Older drivers were classified as having normal cognitive status based on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975).

Subtests of UFOV® (PC version) were administered to measure speed of visual processing (subtest 1), divided attention (subtest 2) and selective attention (subtest 3). The first subtest required the identification of a target (silhouette of a car or truck) presented in a central fixation box. The second subtest required the identification of the central target along with the localization of a simultaneous peripheral target (silhouette of a car or truck). The third subtest used a design similar to the second subtest, but added distracters (triangles of the same size and luminance as the targets) that filled the visual display.

TTA was studied using a removal paradigm: drivers saw a video projection (without sound) of an oncoming vehicle from the right way and had to press a response button (PC) when they judged the vehicle reached a previously established point on the road. They view the scenario that was filmed from a camera in a static position. After 3 practice scenes, participants judged 15 approaches: 10 were used for data collection and 5 were used as distracters. For data collection the car traveled either at 50 or 70 km/h, appeared during 7 s, and was removed from the scenario 3 s before reaching the arrival point. The distracter scene consists of an approaching car at 60 km/h with a display time of 6 s and a removal time of 1.5 s. Accuracy in performance (absolute error, AE), response bias (constant error, CE) and response consistency (variable error, VE) were registered. For a more comprehensive description of the three types of errors evaluated, see Magill (2003).

Statistical Analysis

Variance analysis (ANOVA), contrast and post-hoc Scheffé tests were used to study the differences between age groups. Partial correlations were calculated to study the associations between TTA and UFOV® results. Independent sample *t*-tests were used to compare the results of the TTA estimations in the two different vehicle speed approaches. Comparisons between genders were also performed using independent sample *t*-tests. Significance level was set at $p<0.05$ for all tests.

RESULTS

Useful Field of View

Descriptive statistics for the UFOV® performance is presented in Table 2. Differences between groups were found in divided and selective attention (p's<0.001). Post hoc analysis showed that compared with young and middle-aged drivers, older drivers had poorer results in divided and selective attention (p´s<0.001).

Table 2. UFOV® results in ms (M±SD) for the three age groups.

	Young drivers	Middle-aged drivers	Old drivers
Speed Processing	22.3 ± 21.7	18.8 ± 4.90	43.3 ± 88.6
Divided Attention	30.6 ± 28.4	33.2 ± 31.4	162.8 ± 131.1[a,b]
Selective Attention	84.6 ± 53.3	115.2 ± 47.8	343.9 ± 120.8[a,b]

Note. [a] Old *vs* Young $p<0.001$ [b] Old *vs* Middle-age, $p<0.001$.
Smaller scores reflect better performance.

The data had some nonlinear variation revealing a much more evident decrease in visual attention performance from the middle-aged to the older group than from the younger to the middle-aged group.

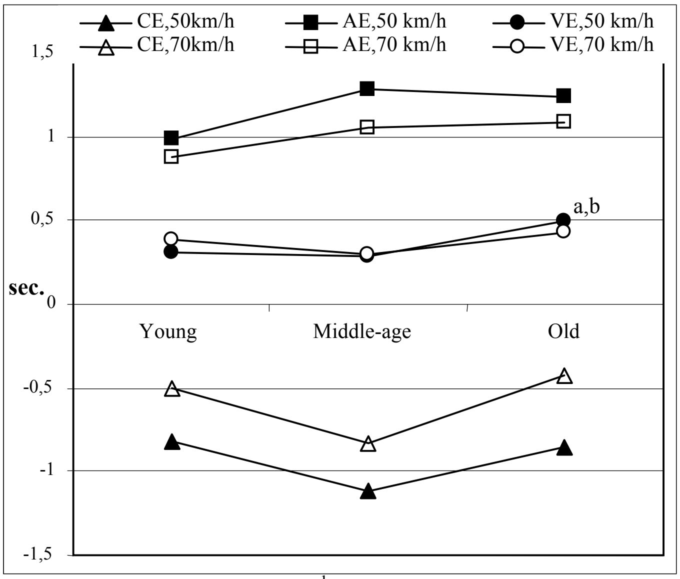
Time-to-Arrival

The error results for the TTA estimations are plotted in Fig. 1. Statistical differences between groups were found for the VE at 50km/h ($p=0.02$). Older adults had greater VE judging a vehicle approaching at 50 km/h when compared with young and middle-aged drivers ($p=0.019$ and $p=0.006$, respectively).

In the comparison between groups of AE at 50 km/h, the differences fell short of reaching statistical significance ($p=0.052$).

The results for CE showed a clear underestimation of TTA, that is, approaching vehicles were estimated to arrive sooner than they actually do. Although not statistically significant, it is also interesting to notice that middle-aged drivers had larger CE and young and older drivers had smaller and very similar CE, showing a U-shaped relationship with age.

In the comparison of measures between the two velocity paradigms (50km/h and 70 km/h), differences were established in the AE ($p=0.039$) and CE ($p=0.013$), respectively. These results showed that the TTA accuracy increased and the response bias decreased when the approaching vehicle travels at higher speeds. When this type of analysis was performed for each age group, the same pattern of results was found.



[a] Old *vs* Young, p<0.001 [b] Old *vs* Middle-aged, p<0.001

Fig. 1. TTA error measures for the three age groups

Relations between UFOV® and TTA

Partial correlation coefficients (controlling for visual acuity) revealed two weak associations between the results in UFOV® and TTA for the total sample: greater VE judging a car approaching at 50 km/h was associated with poorer scores in selective attention (r=0.34, *p*=0.001) and divided attention (r=0.25, *p*=0.019).

Gender effects

When the sample was considered as a single group, no statistically differences between genders were found in the UFOV® scores and TTA estimations.

Statistical analysis was also performed separately for each age group. The results showed that young females had higher AE in the TTA estimations compared with young males. This was observed in both situations when the oncoming vehicle travelled at 50 or 70 km/h (*p*=0.048 and p=0.006, respectively). Young female drivers had also higher CE in the TTA judgments at 50 km/h (*p*=0.049) than young male drivers.

DISCUSSION

In contrast to the results of other studies (e.g., Hancock & Manser, 1997; Leung & Starmer, 2005), there were few statistically significant differences between age groups in the TTA estimations. Significant differences were found only in the VE results, with older drivers showing less consistency than young and middle-aged drivers in estimating the TTA of a vehicle approaching at 50 km/h. It has been proposed that the lower accuracy or more variability in TTA judgments by older drivers, combined with factors like longer times required to cross the road or to perform a turning maneuver, could explain their tendency to be more conservative than young drivers when deciding to enter traffic and accepting larger gaps in order to reduce the probability of a traffic accident (Keskinen, Ota, & Katila, 1998; Scialfa, Kline, Lyman, & Kosnik, 1987; Skaar, et al., 2003). Hence, it should be pointed out that the relative underestimation of TTA might reflect some loss of perceptual abilities, but on the other hand, could prove to be beneficial towards a more preventive behavior (e.g., encouraging drivers to choose large gaps between successive oncoming vehicles) (Hesketh & Godley, 2002).

There was a clear underestimation of TTA in all age groups, and TTA judgments were done with greater accuracy and less variability when the vehicle approached at higher velocity, which confirmed previous conclusions (Caird & Hancock, 1994; Hancock & Manser, 1998; Horswill, Helman, Ardiles, & Wann, 2005). Within the younger group of drivers, females had great error amplitudes than males in various TTA measures. Other investigations reported greater TTA underestimations for female drivers when compared with male drivers (Hancock & Manser, 1997; Leung & Starmer, 2005; Schiff, Oldak, & Shah, 1992). It has been hypothesized that women's TTA estimations are more cautious than men's because they have less confidence in their perceptual-motor response ability and therefore need more time to re-evaluate potential dangerous situations. Recently, it was shown that women tended to evaluate their capabilities in a more negative way than men (Ferreira, Marmeleira, Godinho, & Simões, 2007). Previous studies have also shown that male drivers are more prone to take risks and to be involved in crashes than female drivers (Blockey & Hartley, 1995; Deery, 1999; Elander, West, & French, 1993).

Although not statistically significant, it is interesting to notice that middle-aged drivers had a tendency to underestimate TTA more than young and older drivers (these two groups had similar CE). Given the older drivers' performance in this measure, it seems very unlikely that the middle-aged drivers constitute a special case of visual perceptual difficulties. Thus, other factors may underlie the findings (e.g., a more preventive driving behavior of middle-aged drivers). Future studies should address this issue.

It is important to note that there are evident methodological differences between driving studies that have used TTA paradigms, making it difficult to interpret and generalize of the findings. Some studies only compare young with older drivers (Hancock & Manser, 1997; Schiff, et al., 1992; Skaar, et al., 2003), with the minimum age considered for inclusion in the group of older drivers ranging between 50, 55, and 60 years (DeLucia, Bleckey, Meyer, & Bush, 2003; Hancock & Manser, 1997; Schiff, et al., 1992; Scialfa, et al., 1987; Skaar, et al., 2003), and the removal times have ranged from 1 to 7 s, 3 to 6 s, 1.5 to 6 s, and 4 to 10 s (Caird & Hancock, 1994; Manser & Hancock, 1996; Schiff & Oldak, 1990; Seward, Ashmead, & Bodenheimer, 2006). Finally, various research environments have been used: desktop scenarios, projection of real scenes, simulators or computer-made graphics and real situations (DeLucia, Bleckey, Meyer, & Bush, 2003; Leung & Starmer, 2005; Marmeleira, et al., 2007; Seward, et al., 2006; Skaar, et al., 2003). This diversity of methods is one of the reasons why some reservation subsists about the TTA paradigm effectiveness for the assessment of drivers' abilities. In our opinion, more research is needed to define what type of TTA paradigm design is more appropriate and also to examine closely the associations between performance in this paradigm and driving behavior.

Older drivers showed marked deficits in visual attention. Thus, this negative impact of age was observed for the divide and selective attention conditions. Young and middle-aged drivers had very similar results in the UFOV®. Other authors have reported similar results. Ball et al. (1988) found only slight differences in UFOV® performance between young (22-33 years old) and middle-aged individuals (40-49 years old), but found large performance differences between both groups and a sample of elderly individuals (60-75 years old). Another study (Ponds, Brower, & Van Wolffelaar, 1988) also reported that elderly adults suffered a significant decrease in the ability to divide attention compared with young and middle-aged adults (these two groups showed no differences). Seiple et al. (1996) found similar results, suggesting that critical changes in UFOV occur around 60 years of age.

However, a recent investigation conducted in a driving simulator reported that middle-aged drivers (46-57 years old) already showed a substantial decrease in the UFOV when their performance was compared with that of younger drivers (21-34 years old) (Rogé, Otmani, Pébayle, & Muzet, 2008). These differences were enhanced with larger durations of the driving task. Sekuler et al. (2000) concluded that the UFOV size does not decrease with age but that older people process the received information less efficiently within the UFOV (changes appear to occur gradually during the normal lifespan). According to Rogé et al. (2008), two models of impairment in the UFOV have been considered in the literature: (i) deterioration has been described as a general interference when the decreased performance of the peripheral task is homogeneous over the whole field (constant decrease regardless of the eccentricity at which point the peripheral signal appears); (ii) deterioration has been identified as a phenomenon of tunnel vision when the decrease in the performance of the peripheral task is greater with the increase of eccentricity in peripheral signal to be detected.

The significant reduction of the UFOV around 60 years of age, and the link previously established between UFOV and driving performance and safety in older adults (Anstey, et al., 2005; Clay, 2005; Sims, et al., 2000), should be reflected in more preventive decisions by transportation authorities. For example, the screening protocols for the revalidation of the driving license of older drivers should include the evaluation of functional visual abilities (not visual acuity alone).

Previous investigations showed that it is possible to improve the UFOV. Kooijman et al. (2004), in a study among drivers with visual field defects, reported that a compensatory viewing training (laboratory and mobility training, including driving instruction) improved the driving performance in an on-road test. Ball et al. (1988) reported that the UFOV could be enlarged by 10 degrees with computer-based training; positive effects were demonstrated for young, middle-aged and older drivers and persisted more than six months. It is important to note that physical activity might be a good strategy to improve visual attention. Roth et al. (2003) concluded that individuals who regularly engaged in physical activity had significantly better UFOV® scores than less active individuals. Recently, it was reported that elderly individuals who have expertise in orienteering activities have developed attentional skills that outweigh the age-related changes of visual attentional (Pesce, Cereatti, Casella, Baldari, & Capranica, 2007).

Finally, the associations between UFOV® performance and TTA judgments were weak, corroborating the findings of a recent study (Raghuram & Lakshminarayanan, 2006). Thus, it seems that both tests measure different aspects of the visual information process.

This study has some limitations that must be considered in interpreting the results. As pointed before, the effectiveness of the TTA paradigm for driving assessment is still in discussion. Future research using longitudinal designs is needed to examine whether changes in TTA performance are associated with driving performance and motor vehicle crashes. Additionally, the UFOV® has been used essentially as a tool to measure older drivers' capabilities, but it is still necessary to examine its validity among younger drivers.

CONCLUSION

The present study found that compared with young and middle-aged drivers, older drivers suffered a clear reduction in visual attention. Training programs should be developed to avoid or delay this decline.

Few significant differences were found in the TTA estimations between young, middle-aged and older drivers. Some uncertainties remain on the method effectiveness for the evaluation of driving-related abilities.

REFERENCES

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clin Psychol Rev, 25*(1), 45-65.

Ball, K., & Owsley, C. (1993). The useful field of view test: a new technique for evaluating age-related declines in visual function. *J Am Optom Assoc, 64*(1), 71-79.

Ball, K., Beard, B. L., Roenker, D. L., Miller, R. L., & Griggs, D. S. (1988). Age and visual search: expanding the useful field of view. *J Opt Soc Am A, 5*(12), 2210-2219.

Ball, K., Roenker, D. L., Wadley, V. G., Edwards, J. D., Roth, D. L., McGwin, G., Jr., et al. (2006). Can high-risk older drivers be identified through performance-based measures in a Department of Motor Vehicles setting? *J Am Geriatr Soc, 54*(1), 77-84.

Blockey, P. N., & Hartley, L. R. (1995). Aberrant driving behaviour: errors and violations. *Ergonomics, 38*(9), 1759-1771.

Caird, J., & Hancock, P. (1994). The perception of arrival time for different oncoming vehicles at an intersection. *Ecol Psychol, 6*, 83-109.

Cavallo, V., & Laurent, M. (1988). Visual information and skill level in time-to-collision estimation. *Perception, 17*(5), 623-632.

Clay, O., Wadley, V., Edwards, J., Roth, D., Roenker, D., Ball, K. (2005). Cumulative meta-analysis of the relationship between useful field of view and driving performance in older adults: Current and future implications. *Optom Vis Sci, 82*, 724-731.

Deery, H. A. (1999). Hazard and risk perception among younger novice drivers. *J Safety Res, 30*(4), 225-236.

DeLucia, P. R., Bleckey, M. K., Meyer, L. E., & Bush, J. M. (2003). Judgments about collision in younger and older drivers. *Transp Res: Part F, 6*, 63-80.

Edwards, J. D., Ross, L. A., Wadley, V. G., Clay, O. J., Crowe, M., Roenker, D. L., et al. (2006). The useful field of view test: normative data for older adults. *Arch Clin Neuropsychol, 21*(4), 275-286.

Elander, J., West, R., & French, D. (1993). Behavioral correlates of individual differences in road-traffic crash risk: an examination method and findings. *Psychol Bull, 113*(2), 279-294.

Ferreira, I., Marmeleira, J., Godinho, M., & Simões, M. (2007). *Cognitive factors and gender related to self-reported difficulties in older drivers.* Paper presented at the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Stevenson, Washington.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res, 12*(3), 189-198.

Hancock, P., & Manser, M. (1997). Time-to-contact: More than tau alone. *Ecol Psychol, 9*.

Hancock, P., & Manser, M. P. (1998). Time-to-Contact. In A. M. Feyer & A. M. Williamson (Eds.), *Occupational injury: risk, prevention and intervention* (pp. 44-58). Washington, DC: Taylor and Francis.

Hesketh, B., & Godley, S. T. (2002). A comparison of time estimations in driving with target-only in motion, self-only in motion, and self-and-target in motion. *Ecol Psychol, 14*(3), 111-125.

Horswill, M., Helman, P., Ardiles, P., & Wann, J. (2005). Motorcycle accident risk could be inflated by a time to arrival illusion. *Optom Vis Sci, 82*(8), 740-746.

Kooijman, C., Brouwer, W. H., Coeckelbergh, T. R., Tant, M. L., Cornelissen, F. W., Bredewoud, R. A., et al. (2004). Compensatory viewing training improves practical fitness to drive of subjects with impaired vision. *Vis Impair Res, 6*(1), 1-27.

Lee, D. (1976). A theory of visual control of braking based on information about time-to-collision. *Perception, 5*(4), 437-459.

Leung, S., & Starmer, G. (2005). Gap acceptance and risk-taking by young and mature drivers, both sober and alcohol-intoxicated, in a simulated driving task. *Accid Anal Prev, 37*(6), 1056-1065.

Magill, R. (2003). *Motor Learning and control, concepts and applications* (Seventh ed.). New York: McGraw-Hill.

Manser, M. P., & Hancock, P. A. (1996). Influence of approach angle on estimates of Time to-Contact. *Ecol Psychol, 8*(1), 71-99.

Marmeleira, J., Ferreira, I., Godinho, M., & Fernandes, O. (2007). *Time-to-Arrival and Useful Field of View: associations with self reported driving difficulties among older adults.* Paper presented at the Fourth International Driving Symposium on Human Factors in Driver Assessment, Stevenson, Washington.

Mayhew, D. R., Simpson, H. M., & Ferguson, S. A. (2006). Collisions involving senior drivers: high-risk conditions and locations. *Traffic Inj Prev, 7*(2), 117-124.

McGwin, G., Jr., & Brown, D. B. (1999). Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accid Anal Prev, 31*(3), 181-198.

Owsley, C., Ball, K., McGwin, G., Jr., Sloane, M. E., Roenker, D. L., White, M. F., et al. (1998). Visual processing impairment and risk of motor vehicle crash among older adults. *JAMA, 279*(14), 1083-1088.

Owsley, C., Ball, K., Keeton, D. (1995). Relationship between visual sensitivity and target localization in older adults. *Vision Res, 35*, 579-587.

Owsley, C., Sloane, M., McGwin, G., Jr., & Ball, K. (2002). Timed instrumental activities of daily living tasks: relationship to cognitive function and everyday performance assessments in older adults. *Gerontology, 48*(4), 254-265.

Pesce, C., Cereatti, L., Casella, R., Baldari, C., & Capranica, L. (2007). Preservation of visual attention in older expert orienteers at rest and under physical effort. *J Sport Exerc Psychol, 29*(1), 78-99.

Ponds, R. W., Brower, W. H., & Van Wolffelaar, P. C. (1988). Age differences in divided attention in a simulated driving task. *Journal of Gerontology: Psychological Sciences, 43*, 151-156.

Raghuram, A., & Lakshminarayanan, V. (2006). Motion perceptions tasks as potential correlates to driving difficulty in the elderly. *J Mod Optic, 53*(9), 1343-1362.

Rogé, J., Otmani, S., Pébayle, T., & Muzet, A. (2008). The impact of age on useful visual field deterioration and risk evaluation in a simulated driving task. *Eur Rev Appl Psychol, 58*, 5-12.

Roth, D. L., Goode, K. T., Clay, O. J., & Ball, K. K. (2003). Association of physical activity and visual attention in older adults. *J Aging Health, 15*(3), 534-547.

Sanders, A. F. (1970). Some aspects of the selective process in the functional visual field. *Ergonomics, 13*(1), 101-117.

Schiff, W., & Oldak, R. (1990). Accuracy of judging time to arrival: effects of modality, trajectory, and gender. *J Exp Psychol Hum Percept Perform, 16*(2), 303-316.

Schiff, W., Oldak, R., & Shah, V. (1992). Aging persons' estimates of vehicular motion. *Psychol Aging, 7*(4), 518-525.

Seiple, W., Szlyk, J. P., Yang, S., & Holopigian, K. (1996). Age-related functional field losses are not eccentricity dependent. *Vision Res, 36*(12), 1859-1866.

Sekuler, A. B., Bennett, P. J., & Mamelak, M. (2000). Effects of aging on the useful field of view. *Exp Aging Res, 26*(2), 103-120.

Seward, A. E., Ashmead, D. H., & Bodenheimer, B. (2006). *Discrimination and Estimation of Time-to Contact for Approaching Traffic Using a Desktop Environment.* Paper presented at the Symposium on Applied Perception in Graphics and Visualization, Boston, MA.

Sims, R. V., McGwin, G., Jr., Allman, R. M., Ball, K., & Owsley, C. (2000). Exploratory study of incident vehicle crashes among older drivers. *J Gerontol A Biol Sci Med Sci, 55*(1), M22-27.

Skaar, N., Rizzo, M., & Stierman, L. (2003). *Traffic entry judgments by aging drivers.* Paper presented at the Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Park City, Utah.

Staplin, L., & Lyles, R. (1992). Age differences in motion perception and specific traffic maneuver problems. *Transp Res Rec, 1325*, 23-33.

Tresilian, J. (1994). Approximate information sources and perceptual variables in interceptive timing. *J Exp Psychol Human Percept Perform, 20*(1), 154-173.

Tresilian, J. R. (1999). Visually timed action: time-out for 'tau'? *Trends Cogn Sci, 3*(8), 301-310.

Whelihan, W. M., DiCarlo, M. A., & Paul, R. H. (2005). The relationship of neuropsychological functioning to driving competence in older persons with early cognitive decline. *Arch Clin Neuropsychol, 20*(2), 217-228.

CHAPTER IV

The effects of exercise on driving-related abilities

Article 4. **The effects of an exercise program on several abilities associated with driving performance in older adults**

The effects of an exercise program on several abilities associated with driving performance in older adults

José Marmeleira, Mário Godinho, Orlando Fernandes

Abstract

The purpose of this study was to investigate the effects of participation in an exercise program on several abilities associated with driving performance in older adults. Thirty-two subjects were randomly assigned to either an exercise group (60-81 years, n=16) or a control group (60-82 years, n=16). The exercise program was planned to stress perceptive, cognitive, and physical abilities. It lasted 12 weeks with a periodicity of 3 sessions of 60 minutes per week. Assessments were conducted before and after the intervention on behavioral speed (in single- and dual-task conditions), visual attention, psychomotor performance, speed perception (time-to-contact), and executive functioning. Significant positive effects were found at 12-week follow-up resulting from participation in the exercise program. Behavioral speed improvements were found in reaction time, movement time, and response time (both in single- and dual-task conditions); visual attention improvements took place in speed processing and divided attention; psychomotor performance improvements occurred in lower limb mobility. These results showed that exercise is capable of enhancing several abilities relevant for driving performance and safety in older adults and, therefore, should be promoted.

Key words: Driving, aging, exercise

Accident Analysis and Prevention (2009), 41(21): 90-97.

INTRODUCTION

Considering the data on road crashes and the increase of drivers aged 65 years old or more, researchers as well as diverse public and private entities are showing a greater interest in issues associated with older drivers' fitness to drive and safety. It was reported that older drivers have a high crash rate per distance travelled (Guerrier, Manivannan, & Nair, 1999; Lyman, McGwin, & Sims, 2001; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998) and an increased risk of injury or death in the event of a traffic crash (Li, Braver, & Chen, 2003; McGwin, Sims, Pulley, & Roseman, 2000).

Diverse perceptive, cognitive, and motor factors have been associated with driving difficulties and crash incidence in older adults. In a literature review, Anstey, Wood, Lord, and Walker (2005) reported that measures of attention, reaction time, memory, executive function, mental status, visual function, and physical function were associated with driving outcome measures. Health status (e.g., cardiovascular illnesses, diabetes mellitus, state of depression, and dementia) has also been linked with the occurrence of crashes in older drivers (Adler, Rottunda, & Dysken, 2005; McGwin, et al., 2000; Sagberg, 2006).

Aging is associated with a decline in several cognitive skills and brain functions (Anstey & Low, 2004; Bixby, et al., 2007; Spirduso, Francis, & MacRae, 2005), which can result in driving difficulties. For example, a decline in information processing speed, loss of efficiency in acquiring new information, cognitive inflexibility, a decline in executive functioning, a reduction in attentional resources, and a reduction in working memory function have been demonstrated (Ball, Wadley, Vance, & Edwards, 2004; Spirduso, et al., 2005).

Interestingly, the practice of physical activities has a positive effect on several perceptive, cognitive, and physical abilities as well as on health factors that are considered important for driving performance and safety among older adults. There is strong scientific evidence that physical activity is a key factor for healthful aging, and this is now the official position of internationally recognized institutions (American College of Sports Medicine [ACSM], 1998; World Health Organization [WHO], 1997). For instance, elderly people who are physically fit show greater efficiency in information processing (Etnier, et al., 1997; Kramer, et al., 2002), enhancement of attention capacity in dual-task situations (Hawkins, Kramer, & Capaldi, 1992), and better performance on tasks that demand visual-spatial processing (Shay & Roth, 1992).

The effects of physical activity on cognitive factors seem to be accentuated for tasks that require greater attention resources (Etnier, et al., 1997; van Boxtel, et al., 1997). Chodzko-Zajko and Moore (1994) suggested that, in older adults, aerobic fitness has a larger impact on tasks that require controlled and effortful processing than on tasks that are executed using automatic processing. Furthermore, it was found that tasks pertaining to fluid intelligence were more sensitive to physical fitness than those corresponding to crystallized intelligence (Chodzko-Zajko, 1991).

Although vehicle operations become relatively more automatic with experience, driving is a complex task that involves a variety of skills. Of these skills, the most important are the acquisition and processing of information and the ability to make appropriate and timely decisions based on this information (Olson & Dewar, 2007). In fact, driving is a complex task in which several skills and abilities are involved simultaneously. Given that the types of crashes in which older adults are involved often occur in complex traffic situations such as intersections (Mayhew, Simpson, & Ferguson, 2006; McGwin & Brown, 1999), it is reasonable to hypothesize that difficulties occur at the level of executive function (i.e., the planning and decision-making aspect of the driving task) (Anstey, et al., 2005). Daigneault, Joly, and Frigon (2002) found that drivers who had crashes during the previous five years performed poorly on measures of executive functioning. In the last several years, relevant investigations have indicated that the frontal neural system (region that mediates executive functioning) is the primary locus in which aging-related cognitive deficits are found and that it is also where physical fitness appears to exert its greatest influence (Bixby, et al., 2007; Colcombe & Kramer, 2003; Kramer, et al., 2002).

Several health conditions (e.g., heart disease, arthritis, and diabetes) and medications (e.g., antidepressants, anticoagulants, and benzodiazepines) have been associated with older drivers' involvement in car crashes (McGwin, et al., 2000; Sagberg, 2006). Considering that regular physical activity is effective in reducing/preventing a number of functional declines associated with aging diseases (ACSM, 1998; WHO, 1997), it seems reasonable to presume that exercise could have a positive role in driving safety.

Previous investigations have explored the potential link between physical training and driving-related abilities. Morattoli et al. (2007) demonstrated the possibility of maintaining or enhancing driving performance among physically impaired older drivers (>70 years of age) using a safe, well-tolerated multicomponent physical conditioning program. Ostrow, Shaffron, and McPherson (1992), in a randomized control trial, concluded that an 8-week range-of-motion exercise training program successfully improved older drivers' shoulder flexibility and trunk rotation as well as specific driving skills. Tuokko, Rhodes, and (2007) found that older adults with lower physical activity levels experienced driving difficulties involving the spine and lower body. They found that the most frequently reported symptoms were located in areas highly amenable to modification (spine and lower body) and pointed out that most of the older drivers expressed a willingness to engage in exercise programs if an association between physical fitness and driving could be demonstrated.

According to Taylor and Dorn (2006), there are several ways in which the increase of physical activity may improve driving performance and potentially reduce crash risk; these include diminishing stress, enhancing sleep and alertness, reducing fatigue, improving cognitive functioning, and enhancing psychological and physical health status. Some studies reported that sport practice is related to improvements in specific aspects of driving behavior, namely, visual perception (Matos & Godinho, 2005, 2007) and performance in context (Hancock, Kane, Scallen, & Albinson, 2002). Recently, Matos and Godinho (2007) showed that a specific perceptual-motor training program could enhance the useful field of view and peripheral reaction time in novice drivers, suggesting that exercise that requires demanding information treatment and in which event perception is crucial could be positively transferred to driving situations.

It is important to point out that the cross-sectional nature of several studies that compared exercisers with non-exercisers complicates the interpretation of results since the positive effects of physical fitness on perceptual, cognitive, and motor performance may reflect a predisposition of the exercisers toward fast and accurate responding rather than a benefit of aerobic fitness achieved through exercise (ACSM, 1998; Etnier, et al., 1997; Kramer, et al., 2002). Also, a great deal of research has focused on elderly drivers' crash-involvement patterns, but not on the development and evaluation of methods that may enhance their driving-related abilities. In fact, of the interventions directed toward older drivers’ capabilities in which physical activity/mobilization represents the main strategy, most of the research has focused on specific abilities related to range of motion and mobility, especially in populations with physical impairments.

In our view, it is necessary to expand upon the goals, methods, and participant characteristics of interventions in which exercise constitutes the central tool in improving the fitness to drive. A recent systematic literature review (Kua, Korner-Bitensky, Desrosiers, Man-Son-Hing, & Marshall, 2007) suggested that the use of skill-specific training may play an important role in re-training older adults on driving skills and that multi-faceted programs that incorporate physical, perceptive, and educational training should be promoted.

Although the scientific literature supports the claim that exercise has the potential to benefit several important physical, perceptive, and cognitive factors related to driving in older adults, we have not found experimental studies containing exercise interventions intended to concurrently enhance several abilities relevant for driving. In this context, the main aim of this research is to study the effects of a specific exercise program on several abilities important for the driving performance and safety of older adults.

METHODS

Participants

Participants were recruited in the region of Évora (Portugal) by posted flyers and local radio/newspaper announcements. Questionnaires were administered to gather information on demographic variables, physical activity practice, driving habits, functional impairments, and medical conditions. The inclusion criteria for participants were: aged 60 years or more; live independently in the community; healthy without serious cardiovascular or musculoskeletal disease; possess a valid driving license; 20/40 or greater corrected binocular vision measured with a Snellen Chart; normal cognitive status on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975); and no engagement in any exercise program for at least one year. An exercise program was defined as any type of physical activity that is planned and structured, occurring at least one day per week.

Three subjects were excluded according to the following criteria: severe osteoarthritis (n=1) or refused to participate (n=2). The remaining 32 subjects were randomly assigned to either the control group (CG, n=16) or the experimental group (EG, n=16). The minimum age was 60 years in both groups and the maximum age was 81 and 82 years in the EG and the CG group, respectively. The groups' characteristics were similar (Table 1).

Table 1. General sample characteristics

	Control Group	Exercise Group	*p*
N	16	16	
Female, Male	3, 13	4, 12	0.41[a]
Age (years)	68.4 (6.7)	68.2 (6.5)	0.94
Education (years)	5.1 (2.2)	4.8 (3.1)	0.79
Visual Acuity (decimal)	1.1 (0.3)	1.0 (0.3)	0.49
MMSE (points)	28.4 (1.5)	28.6 (1.1)	0.90
Time with driving licence (years)	32.7 (13.5)	31.8 (11.3)	0.86
Weekly distance driven (km)	99.0 (77.8)	112.3 (98.5)	0.65

[a]*Chi-Square test*

Procedures

The study protocol included a battery of motor, perceptive, and cognitive tests that intend to measure abilities relevant to driving performance and safety among older adults. At baseline and after 12 weeks, each subject performed the tests and questionnaires in two sessions of approximately 60 min each. The order of application was the same at baseline and after 12 weeks.

During the entire 12-week period, the CG continued to follow normal daily activities. Participants were assured that the research results were confidential and had no bearing on their driving licence. Prior to participation, the study was explained, and written informed consent was obtained from each participant. This study was approved by the institutional Human Research Ethics Committee. All procedures were followed according to the Declaration of Helsinki.

Single-task condition

For the *simple reaction time* testing, the participants were sat comfortably on a chair and grasped a steering wheel. They were instructed to react as quickly as possible to stimuli using the right foot to manage the accelerator and brake pedals. A real scene that was filmed in an urban context from inside a car travelling at a moderate velocity (± 50 km/h) behind another car was used. From time to time, the leading car's rear brake lights were activated. The total film was 360 s, and, during that period, the participant had to respond to 25 onsets of the rear brake lights (1 for practice and 24 for data acquisition) of the front vehicle. In order to create temporal uncertainty, the time intervals between the stimulus signs were randomized (minimum of 8 s and maximum of 16 s). The film was projected onto a screen covering approximately 25 degrees horizontal and 20 degrees vertical of the subjects' visual field.

The foot pedal data were collected using microswitches, which were connected to a MP100 Biopac® data acquisition system that was associated with a PC. The input of the accelerator was registered when it was initially released; the signal from the brake pedal was detected when it was completely depressed. In order to synchronize the data acquisition from film events and foot pedal actions, an audio sign was added (by means of a video editor software) to the exact beginning of each rear break lights onset and an additional audio cable linked the PC to the Biopac® system. All signs were detected and treated with Acqnowledge® 3.7.2 software.

Reaction time (in ms) was measured from the onset of the leading car brake lights to the initial release of the accelerator by the driver participant. Movement time (in ms) was the period from the initial release of the accelerator to the full brake application. Response time (in ms) was measured from the onset of the leading car brake lights to the full brake application.

For data analysis, the upper bound of each time component measure was established by computing the mean and standard deviation separately for each group (CG and EG, baseline and after 12 weeks) and dropping any trial exceeding the mean by three or more standard deviations (Hultsh et al., 2002). A lower bound for legitimate responses was set at 150 ms, and scores below this limit were dropped.

For the *choice reaction time* testing, two- and three-choice reaction tasks were used. Real scenes were filmed from inside a car travelling at a moderate velocity (± 50 km/h) behind another car in an urban context. Participants were instructed to react as quickly as possible. In the two-choice condition, the stimuli were: (i) the leading car rear brake lights are activated and (ii) a person suddenly cuts across from the right side just in front of the participant's vehicle. In the first condition, the participant should brake; in the second condition, the participant should steer the wheel to the left in order to avoid the unexpected pedestrian. For the three-choice reaction time task, another stimulus was added: (iii) a person suddenly appears from the left side. In this situation, the participant should steer the wheel to the right in order to avoid the unexpected pedestrian.

Twenty-five short films (1 for practice and 24 for data acquisition) were prepared for each choice reaction time task. The occurrence of each stimulus type was balanced. To create temporal and occurrence uncertainty, the stimulus type and the time intervals (minimum of 5 s and maximum of 14 s) were randomized between each trial.

Performance measures and general procedures were similar to those used in the simple reaction task condition, with the exception of one upgrade: a microswitch was attached to the steering wheel and connected to the Biopac® system, making possible the instantaneous detection of movement and respective direction.

Dual-task condition

The primary task was similar to the single-task condition (i.e., the participant had to brake as fast as possible whenever the leading car rear brake lights were activated), and the film used was the same as for the single-task condition. For the secondary task, a summing task adapted from Chaparro, Wood, and Carberry (2005) was used. The task required participants to verbally report the sum of pairs of numbers presented by the researcher. In order to guarantee a more similar mental workload among participants with different mental calculation capabilities, a new pair of numbers was presented immediately after the participant answered the previous problem. All participants completed the dual-task condition after the single-task. Performance measures and general procedures were similar to those of the single-task condition.

Useful Field of View

The three subtests of UFOV® (PC version) were administered to measure speed of visual processing (subtest 1), divided attention (subtest 2), and selective attention (subtest 3). The first subtest requires the identification of a target (silhouette of a car or truck) presented in a central fixation box. The second subtest measures divided attention and involve the identification of the central target along with the localization of a simultaneous peripheral target (silhouette of a car or truck). The third subtest consists of these same two tasks, but also includes visual distracters (triangles of the same size and luminance as the targets) that fill the rest of the visual display. Data were collected in time (ms). Several studies support that impairments in the useful field of view are associated with higher crash risk (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Owsley, Ball, Sloane, Roenker, & Bruni, 1991; Sims, McGwin, Allman, Ball, & Owsley, 2000) or poorer on-road driving performance (Whelihan, DiCarlo, & Paul, 2005).

Time-to-contact

Target-only in motion (Hesketh & Godley, 2002) was studied using a removal paradigm in which drivers saw a video projection (without sound) of an oncoming vehicle from the right direction and had to press a response button (PC) when they judged that the vehicle reached a previously established point on the road. They viewed the scenario filmed from a camera in a static position. After three practice scenes, participants judged 15 approaches: 10 were used for data collection, and 5 were used as distracters. For data collection, the car travelled either at 50 or 70 km/h, appeared during 7 s, and was removed from the scenario 3 s before reaching the arrival point. The distracter scene consists of an approaching car at 60 km/h with a display time of 6 s and a removal time of 1.5 s.

Self-only in motion (Hesketh & Godley, 2002) was studied using an occlusion paradigm in which drivers saw a projection of a film recorded from inside a car in motion and had to press a response button (PC) when they judged that they would pass a truck that was stopped at the right side of the road (at a junction). After three practice scenes, participants judged 15 approaches: 10 were used for data collection, and 5 were used as distracters. For data collection, the car travelled either at 40 or 60 km/h, appeared during 6 s, and the scenario occlusion (black screen) occurred 1.5 s before reaching the arrival point. The distracter scene consists of an approaching car at 50 km/h with a display time of 5 s and an occlusion time of 1.5 s.

Accuracy in performance (absolute error, AE), response bias (constant error, CE), and response consistency (variable error, VE) were registered (in ms). For a more comprehensive description of the three types of errors evaluated, see Magill (2003). Speed and motion perception have also been pointed to as important abilities for safe driving (Hesketh & Godley, 2002; Manser & Hancock, 1996).

Foot Tap Test

This task assesses lower limb mobility, which is associated with the occurrence of adverse driving events (Marottoli, Cooney, Wagner, Doucette, & Tinetti, 1994). While remaining seated, the participant was required to rapidly touch the floor on alternating sides of a 2-inch tall barrier 10 times with his or her right foot. Time (in s) to complete the test was measured. It has been observed that older adults who are physically active perform better on psychomotor tests and that psychomotor functions are relevant to driving (Marottoli & Drickamer, 1993).

Timed Up and Go Test

This test is designed to measure basic mobility function. Subjects were seated with their back against the chair. They were instructed to stand up, walk three meters (at a rapid but comfortable speed) to a mark on the floor, turn around, walk back to the chair, and sit down. Time (in s) to complete the test was measured. According to Marottoli et al. (1994), a gait that is significantly slowed could be indicative of a higher risk of falling, which is related to crash risk as well.

Functional Reach Test

This test is a measure of balance. Beginning in a standing position with an arm fully extended at shoulder height and raised in front of the body, participants were instructed to reach as far as possible maintaining the same hand height level. Outcome was the difference (in cm) between arm's length and maximal forward reach, using a fixed base of support. History of falls was previously associated with driving difficulties in older drivers (Lyman, et al., 2001).

Trail Making Test, part B

The participant used a pencil to sequentially connect a mix of integers and letters that are distributed across a page in an alternating and ascending order (i.e., 1-A-2-B, and so on). Participants were instructed to do the task as quickly as possible and without lifting the pencil from the paper. The time (in s) to complete each sequence was recorded. Associations between the Trail Making Test and driving performance were previously established (Kantor, Mauger, Richardson, & Unroe, 2004).

Stroop Color-Word Test

In the present work, we used the task version described by Salthouse and Meinz (1995). It includes three conditions, each of which was presented on a page with two columns of 10 stimuli each: the baseline condition, consisting of crosses (XXX) where participants were required to name the color of the Xs; the congruent condition in which the word named the ink color in which it was printed (e.g., the word ‘‘RED’’ printed in red ink); and the incongruent condition in which the word named a color incongruent with the ink color in which it was printed (e.g., the word ‘‘RED’’ in green ink). The total time (in s) to correctly name all of the items in each condition was measured. An interference score was calculated, obtained by subtracting the time required to complete the baseline condition from the time required to complete the incongruent condition. A higher positive difference indicated greater interference. Daigneault et al. (2002) reported that drivers who had crashes during the previous five years performed poorly on measures of executive functioning, including a Stroop Color-Word test version.

Exercise intervention

After the baseline evaluation, the EG participated in a supervised exercise program three days a week for 12 weeks. Each session lasted approximately 60 minutes. The exercise intervention was planned to stress not only physiological systems but also perceptive and cognitive mechanisms. With this in mind, the design of the sessions intended to guarantee stimuli relevant to energetic capabilities (e.g., aerobic fitness) and, concurrently, to incorporate physical tasks that induced the participants to solve tasks and respond to challenging situations (e.g., anticipation of events, planning, and decisional effortful tasks) by producing the desirable motor responses. The idea was that physical activities that make large cognitive demands may influence cognition more than repetitive and cyclic activities (Spirduso, 2006).

Some examples of these types of activities are: dual-task situations (e.g., walking in different directions while executing another motor task with the arms); activities that work peripheral vision (e.g., maintaining several balloons in the air); actions that require planning efforts and decision making (e.g., orienteering in the gymnasium and in an open space); activities strongly dependent on working memory (e.g., selecting and completing a specific walking course in the gymnasium after the presentation of the associated auditory signal; auditory cues-walking courses correspondence was previously established); tasks that target speed processing (e.g., while walking, different auditory/visual signs are presented that imply fast and specific psychomotor responses); activities focused on response inhibition (e.g., while maintaining balloons in the air, all auditory numeric signs but one require rapidly catching specific coloured balloons). During numerous activities, open skills were essential because the environment was constantly changing, and movements must be continually adapted (e.g., collective ball games).

It is important to point out that the great majority of activities were performed by the participants while walking (at different rhythms) in the gymnasium or in an open space. All participants used pedometers (New Lifestyles Digi-Walker SW-200), and the training volume was characterized as steps per session. The pedometers also function as a motivation tool (De Cocker, De Bourdeaudhuij, & Cardon, 2008).

In summary, in the present research, a specific exercise program was conceived with the purpose of enhancing various abilities relevant to driving fitness in older adults. The program included different forms of activities that were incorporated in a dynamic and "physical" way.

Statistical analysis

Data normality was evaluated by Kolmogorov-Smirnov Test. Independent Sample *t*-test or the corresponding non-parametric Mann-Whitney test was used (i) to study differences at baseline between the CG and the EG and (ii) to study differences in the 12-week changes between both groups. Paired sample *t*-test or the corresponding non-parametric Wilcoxon signed-rank test was used to compare data within each group at baseline and after 12 weeks. The results are expressed as means (standard deviation). Significance was set at 0.05 ($p<0.05$) for all tests. Statistical analysis was carried out using SPSS 13.0 for Windows (SPSS, Chicago, IL).

RESULTS

At 12-week follow up, data were available from all participants from the EG and the CG. Compliance in the exercise sessions was excellent, exceeding 85% for all participants. Concerning volume training, the EG participants completed 3060 (± 840) steps/session. The tendency was to increase volume per session from baseline to week 12: first 4 weeks, 2874 (747) steps/session; 5th to 8th weeks, 3055 (807) steps/session; 9th to 12th weeks, 3290 (733) steps/session.

At baseline, the EG and CG did not show any statistical difference in the driving-related variables. Several within and between groups differences were found after 12 weeks (Table 2).

Single-task condition. After 12 weeks, significant improvements were found among the EG in reaction time (-7%; p=0.01), movement time (-15%; p=0.002), and response time (-10%; p=0.001). Inter-group analysis indicated that after 12 weeks, the improvements of the EG was significantly greater than those of the CG for movement time (-15% vs. 2%; p=0.026) and response time (-10% vs. 0%; p=0.035).

Dual-task condition. After 12 weeks, the EG showed significant improvements in reaction time (-11%; p=0.001), movement time (-16%, p=0.001), and response time (-13%; p<0.001). Inter-group analysis indicated that after 12 weeks, the EG improvements were significantly greater than those of the CG for reaction time (-11% vs. 1%; p=0.018) and response time (-13% vs. -2%; p=0.018).

Visual attention. When the comparisons were made at week 12, a significant improvement was observed within the EG in speed processing (-66%; p=0.004) and divided attention (-50%; p=0.002). After 12 weeks, the improvement of the EG was significantly greater than that of the CG for speed of visual processing (-66% vs. 2%; p=0.032).

Psychomotor tests. Foot Tap performance was significantly enhanced within the EG from baseline to week 12 (-15%; p=0.002).

Other measures. For all of the other outcomes, namely, time-to-contact and executive functions, differences were not found within and between groups.

Table 2. Measurements at baseline and at 12 weeks.

	Control Group		Exercise Group		
	Baseline	12 Weeks	Baseline	12 Weeks	p^a
Single-task condition					
Reaction time (ms)	397.2 (61.8)	389.6 (45.7)	405.2 (49.4)	377.7 (35.6) *	0.238
Movement time (ms)	315.3 (88.2)	321.4 (108.5)	311.8 (64.5)	263.5 (68.5) †	0.026
Response time (ms)	712.9 (130.0)	710.6 (135.7)	717.0 (97.4)	641.8 (92.4) *	0.035
2 choice reaction time (ms)	624.5 (49.7)	628.5 (80.0)	599.5 (75.3)	584.1 (72.3)	0.429
3 choice reaction time (ms)	596.6 (65.4)	621.3 (86.3)	611.1 (84.4)	605.5 (72.2)	0.137
Dual-task condition					
Reaction time (ms)	544.0 (136.2)	551.6 (94.3)	550.1 (110.9)	489.8 (68.0) *	0.018
Movement time (ms)	333.9 (107.6)	305.4 (79.6)	297.8 (96.8)	248.9 (61.4) *	0.344
Response time (ms)	875.7 (217.9)	856.4 (158.7)	845.2 (180.2)	736.9 (115.8) *	0.018
UFOV®					
Speed Processing (ms)	45.0 (79.5)	45.9 (80.0)	54.6 (72.6)	18.6 (3.4) †	0.032[b]
Divided Attention (ms)	114.0 (89.2)	73.0 (74.0)	180.0 (124.9)	89.4 (64.8) *	0.123
Selective Attention (ms)	316.9 (156.8)	265.2 (130.0)	335 (131.9)	304.7 (129.7)	0.618
Psychomotor tests					
Foot Tap Test (s)	5.21 (1.20)	5.06 (0.91)	4.84 (0.55)	4.13 (0.46) *	0.547
Timed Up and Go Test (s)	6.51 (0.59)	6.65 (0.72)	6.11 (0.63)	5.91 (0.63)	0.063
Functional Reach Test (cm)	30.67 (5.11)	28.54 (5.39)	29.36 (5.07)	29.35 (6.47)	0.105
Target-only in motion					
AE (ms)	1.30 (0.60)	1.42 (1.25)	1.25 (0.63)	1.28 (0.67)	0.805
CE (ms)	-0.09 (1.44)	0.20 (1.91)	-0.44 (1.34)	-0.50 (1.37)	0.443
VE (ms)	0.55 (0.37)	0.56 (0.37)	0.55 (0.37)	0.53 (0.33)	0.841
Self-only in motion					
AE (ms)	1.22 (0.61)	1.27 (0.66)	1.52 (0.57)	1.53 (0.57)	0.791
CE (ms)	-1.00 (0.91)	-0.84 (1.17)	-1.32 (0.97)	-1.33 (0.95)	0.444
VE (ms)	0.42 (0.19)	0.44 (0.28)	0.41 (0.30)	0.30 (0.25)	0.158
Trail Making Test, part B					
Time (s)	146.9 (95.8)	145.9 (91.4)	137.8 (80.4)	122.8 (72.3)	0.495
Errors	2.1 (2.1)	1.8 (1.8)	2.4 (1.9)	2.0 (1.9)	0.954
Stroop Color-Word Test					
Incongruent (s)	38.08 (13.72)	37.27 (15.23)	36.68 (8.42)	33.38 (12.66)	0.423[b]
Interference Score (s)	22.70 (11.68)	20.56 (11.33)	18.89 (9.64)	15.91 (9.54)	0.728[b]

* $p \leq 0.01$ changes within the group. Paired sample *t*-test

† $p < 0.01$ changes within the group. Wilcoxon signed-rank test

[a] *p* values for differences in the 12-week changes between the control group and the exercise group. Independent sample *t*-test except when indicated

[b] Mann-Whitney test

DISCUSSION

The results showed that a specific exercise program is capable of enhancing some important abilities for driving performance (and safety) in older adults. After 12 weeks of intervention, significantly positive effects occurred in behavioral speed (in single and dual-task conditions), visual attention, and lower limb mobility.

In the literature analysis, we did not find any previous research that studied the effects of an exercise program on behavioral speed of older adult drivers on a specific driving task. Hancock et al. (2002) have studied some matching variables in a braking task experiment; however, the drivers were young adults (M=20.4 years, SD=1.3). Curiously, they did not find any advantage of skilled sport practitioners in comparison with non-practitioners on measures of reaction, movement, and response time. According to Hancock et al. (2002), the advantage from sports participation on the driving task is not the ability to behave (e.g., move limbs, react) but the ability to produce the desirable performance in context.

In the present research, significant improvements were found on many measures of behavioral speed, which were studied with the single and dual-task conditions and also with the psychomotor foot tap test. Behavioral speed consists of two major components: reaction time to environmental stimuli and speed of execution (Spirduso, et al., 2005). It is well known that behavioral speed slows with aging and that the correlations of age to reaction time are generally moderate to high, which could affect the way people perform daily functional tasks such as automobile driving (Spirduso, et al., 2005). Green (2000) suggested that a behavioral-slowing trend occurs with aging, which is reflected in greater brake reaction times. Research regarding physical activity has reported better performances on simple and choice reaction tasks among active older adults compared with inactive subjects (ACSM, 1998; Dustman, Emmerson, & Schearer, 1994; Spirduso, 2006). However, according to the ACSM (1998), the cross-sectional nature of many of these studies makes it difficult to interpret the results.

Older drivers may try to compensate for their poorer behavioral speed by driving more slowly (Green, 2000). Furthermore, it seems reasonable to consider that there are unexpected situations in driving that require quick psychomotor responses in order to avoid crashes. Indeed, it would be beneficial for individuals to follow a defensive driving behavior and, at the same time, be capable of quicker appropriate responses in critical driving spacio-temporal constraints. McKnight and McKnight (1999) found a moderate correlation between reaction time and on-road driving performance, with larger associations established for complex reaction times than for simple ones. In the present study, the two- and three-choice reaction time tasks did not show significant differences between the EG and the CG. However, despite the lack of statistical significance, the EG showed progressions along the intervention, while the CG declined in reference to the baseline level. Considering this trend, it seems realistic to expect larger improvements if the exercise program had been extended in time.

For performing complex tasks such as driving, changes in visual attention that often characterize older adults could lead to marked difficulties (Anstey, et al., 2005; Ball, et al., 1993; Owsley, et al., 1991). Driving in traffic requires the ability to attend to relevant information and ignore irrelevant information, often in complex visual scenes with potential hazards occurring in any part of the visual field. Therefore, the speed at which visual information is processed may be an important factor for successfully negotiating difficult or dangerous traffic situations (Anstey et al., 2005). Unfortunately, previous studies report that older drivers showed a significantly decreased ability to divide attention (Ball, et al., 1993; Brouwer, Waterink, Van Wolffelaar, & Rothengatter, 1991). In the present study, after a 12-week intervention, it was possible to significantly improve speed processing and divided attention. This is a very important outcome because the lower visual attention performance of older drivers could put them at a greater risk since several studies support that impairment in the useful field of view is associated with crash involvement (Ball, et al., 1993; Owsley, et al., 1991; Sims, et al., 2000) or poorer on-road driving performance (Whelihan, et al., 2005). Previous studies have also reported encouraging relations between exercise and visual attention (Chodzko-Zajko, 1991; Dustman, et al., 1994; Roth, Goode, Clay, & Ball, 2003). Hawkins et al. (1992) concluded that a 10-week aerobic program exerted a beneficial influence on the efficiency of attentional processes in older adults. Perhaps the participation in exercise programs can provoke brain-vascular and neuro-chemistry benefits that will enable the preservation of the attention function in older adults (Chodzko-Zajko, 1991; Dustman, et al., 1994).

Dual-task deficits are frequently observed in older adults, a group that manifests larger inter-individual variability than younger adults (Bherer, et al., 2005; Chaparro, et al., 2005). Secondary tasks appear to interfere with driving, affecting the detection of hazards and changes in the driving scene (Recarte & Nunes, 2003). This interference translates into an effect on driving performance in real-world driving conditions (Chaparro, et al., 2005). It is promising that research has revealed that dual-task deficits can be reduced, either by specific cognitive training (Bherer, et al., 2005) or aerobic exercise (Hawkins, et al., 1992). Our study corroborates these findings since the exercise program was effective in improving driving performance while exposing older drivers to a secondary cognitive task. The skill transfer from the exercise program to a specific driving task is very encouraging and reinforces previous findings that improvements in attention performance resulting from dual-task training is generalizable to new task combinations involving new stimuli (Bherer, et al., 2005).

Several studies have associated driving difficulties among older adults with physical measures of mobility and balance (Lyman, et al., 2001; Marottoli, et al., 1994; Marottoli & Drickamer, 1993; Sims, McGwin, Pulley, & Roseman, 2001). The present exercise intervention showed that it is possible to improve movement speed, which is confirmed by the results of the Foot Tap Test and also by the reduced movement time in the simple and dual-task conditions. The Timed Up and Go Test and Functional Reach Test, which have been frequently associated with the occurrence of falls among older adults (e.g., Huang, Gau, Lin, & George, 2003), did not show any significant improvement. However, it is relevant that in the first mentioned test, the 12-week differences in change between groups were close to statistical significance, with an obvious advantage for the exercise group.

Concerning time-to-contact, the present study did not give evidence of any positive effect on speed perception resulting from the participation in the exercise program. Moreover, the data at baseline and at 12 weeks were very similar within groups. These results seem consistent with the ecological approach which considers that time-to-contact primarily involves the local transformation of optical information through changes in the size of the image on the retina (Hesketh & Godley, 2002; Manser & Hancock, 1996). This type of approach excludes the necessity of time-to-contact to be explicitly "computed" by the nervous system. If time-to-contact is an invariant characteristic associated with direct perception, then few alterations should be expected when it is measured under the same conditions at two different moments. Furthermore, it would be difficult to claim that training programs could enhance it.

Executive functions are an example of cognitive factors that have been considered relevant to driving (Anstey, et al., 2005; Daigneault, et al., 2002; Whelihan, et al., 2005). Executive functions are necessary to plan and coordinate sensorimotor and cognitive responses to complex driving situations, and they require adequate working memory resources so that relevant information may be held in mind during the decision-making process (Anstey et al., 2005). Despite prior research findings that executive functioning is positively influenced by physical activity (Bixby, et al., 2007; Colcombe & Kramer, 2003; Kramer, et al., 2002), an intervention effect was not evident in the present study. Unlike traditional exercise interventions that generally justify hypothetical improvements in executive functions indirectly via aerobic training, we intended to directly target these abilities, mainly via behavioral motor tasks (e.g., orienteering). Perhaps, these high order cognitive functions need greater practice time in order to reflect improvements. Colcombe and Kramer (2003), in a meta-analytic study, reported that the participation in relatively brief training programs (1-3 months) provided at least as much benefit on cognitive performance as moderate training (4-6 months), but not quite as much as long-term training programs (6+ months). Also, cross-sectional investigations have typically provided more convincing evidence for the effects of physical activity on cognition as compared to intervention studies (Dustman, et al., 1994; Etnier, et al., 1997).

Many of the investigations that incorporate physical training interventions have studied the effect of aerobic exercise on specific pathologies or physical impairments. At the same time, exercise interventions directed toward impairments in cognitive and physical domains have generally been evaluated separately. However, there is evidence that combined cognitive and physical impairments result in a greater increase in disability than either impairment alone (Gill, Williams, Richardson, & Tinetti, 1996). If it is possible to provide exercise programs that are capable of targeting both the cognitive and physical domains, there could be improvements in the independence and mobility of elderly people, allowing them to be more capable of and adaptable in performing complex tasks like driving.

The present study has some limitations, and caution should be taken in generalizing the findings. A relatively small sample of subjects participated, and, despite the use of various measures that have been related to driving, actual driving was not compared before and after the exercise intervention. Also, it was not possible to differentiate between contributions to the obtained improvements by specific characteristics of the exercise program and the expected development of physical fitness that occurred along the 12 weeks of participation. In the future, general measures of physical fitness should be gathered (especially aerobic fitness), and interventions should involve at least one additional sample group that will engage in a typical aerobic exercise program.

Previous studies have found associations between physical activity or mobility with driving (Marottoli, Ness, et al., 2007; Sims, et al., 2001) and have also reported that physical activity (or the lack of) is a modifiable factor that is driving-related through its relevance on several health conditions or symptoms (Taylor & Dorn, 2006; Tuokko, et al., 2007). Nevertheless, the research approach that emphasises the influence of physical activity on driving capability has been specific, studying associations between the driving task and motor functions (often in populations with some type of impairments) and has not assumed a broader perspective that intends to achieve beneficial exercise effects on several abilities relevant for driving performance.

The maintenance of mobility among older adults is a growing area of concern, and transportation mobility is an important source of independence for older adults (Dickerson, et al., 2007; Tuokko, et al., 2007). In the present study, a specific exercise program that incorporated open skills and more demanding perceptive and cognitive activities than many of the traditional closed and cyclic physical activities was successful in improving several abilities considered critical for driving performance and safety among older adults.

REFERENCES

Adler, G., Rottunda, S., & Dysken, M. (2005). The older driver with dementia: An updated literature review. *J Safety Res, 36*(4), 399-407.

American College of Sports Medicine (2008). Position Stand: Exercise and physical activity for older adults. *Med Sci Sports Exerc, 30*(6), 992-1008.

Anstey, K., & Low, L. (2004). Normal cognitive changes in aging. *Aust Fam Physician, 33*, 783-788.

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clin Psychol Rev, 25*(1), 45-65.

Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Invest Ophthalmol Vis Sci, 34*(11), 3110-3123.

Ball, K., Wadley, V., Vance, D., & Edwards, J. (2004). Cognitive skills: training, maintenance, and daily usage. In C. Speilberg (Ed.), *Encylopedia of Applied Psychology* (pp. 387-392): Elsevier Science.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: are there age-related differences in plasticity of attentional control? *Psychol Aging, 20*(4), 695-709.

Bixby, W. R., Spalding, T. W., Haufler, A. J., Deeny, S. P., Mahlow, P. T., Zimmerman, J. B., et al. (2007). The unique relation of physical activity to executive function in older men and women. *Med Sci Sports Exerc, 39*(8), 1408-1416.

Brouwer, W. H., Waterink, W., Van Wolffelaar, P. C., & Rothengatter, T. (1991). Divided attention in experienced young and older drivers: lane tracking and visual analysis in a dynamic driving simulator. *Hum Factors, 33*(5), 573-582.

Chaparro, A., Wood, J. M., & Carberry, T. (2005). Effects of age and auditory and visual dual tasks on closed-road driving performance. *Optom Vis Sci, 82*(8), 747-754.

Chodzko-Zajko, W. J. (1991). Physical fitness, cognitive performance, and aging. *Med Sci Sports Exerc, 23*(7), 868-872.

Chodzko-Zajko, W. J., & Moore, K. A. (1994). Physical fitness and cognitive functioning in aging. *Exerc Sport Sci Rev, 22*, 195-220.

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci, 14*(2), 125-130.

Daigneault, G., Joly, P., & Frigon, J. Y. (2002). Executive functions in the evaluation of accident risk of older drivers. *J Clin Exp Neuropsychol, 24*(2), 221-238.

De Cocker, K., De Bourdeaudhuij, I., & Cardon, G. (2008). The effect of pedometer use in combination with cognitive and behavioral support materials to promote physical activity. *Patient Educ Couns, 70*(2), 209-214.

Dickerson, A., Molnar, L., Eby, D., Adler, G., BÈdard, M., Berg-Weger, M., et al. (2007). Transportation and aging: A research agenda for advancing safe mobility. *The Gerontologist, 47*(5), 578.

Dustman, R., Emmerson, R., & Schearer, D. (1994). Physical Activity, age, and cognitive neuropsychological function. *J Aging Phys Act, 2*, 143-181.

Etnier, J. R., Salazar, W., Landers, D. M., Petruzzello, S. J., Han, M., & Novell, P. (1997). The influence of physical fitness and exercise upon cognitive functioning: a meta analysis. *J. Sport Exerc. Psychol., 19*, 249-277.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res, 12*(3), 189-198.

Gill, T. M., Williams, C. S., Richardson, E. D., & Tinetti, M. E. (1996). Impairments in physical performance and cognitive status as predisposing factors for functional dependence among nondisabled older persons. *J Gerontol A Biol Sci Med Sci, 51*(6), M283-288.

Green, M. (2000). How long does it take to stop? Methodological analysis of driver perception-brake times. *Transport Hum Factors 2*(3), 195-216.

Guerrier, J. H., Manivannan, P., & Nair, S. N. (1999). The role of working memory, field dependence, visual search, and reaction time in the left turn performance of older female drivers. *Appl Ergon, 30*(2), 109-119.

Hancock, P. A., Kane, M. J., Scallen, S., & Albinson, C. B. (2002). Effects of gender and athletic participation on driving capability. *Int J Occup Saf Ergon, 8*(2), 281-292.

Hawkins, H. L., Kramer, A. F., & Capaldi, D. (1992). Aging, exercise, and attention. *Psychol Aging, 7*(4), 643-653.

Hesketh, B., & Godley, S. T. (2002). A comparison of time estimations in driving with target-only in motion, self-only in motion, and self-and-target in motion. *Ecol Psychol, 14*(3), 111-125.

Huang, H., Gau, M., Lin, W., & George, K. (2003). Assessing risk of falling in older adults. *Public Health Nurs, 20*(5), 399-411.

Kantor, B., Mauger, L., Richardson, V., & Unroe, K. (2004). An analysis of an older driver evaluation program. *J Am Geriatr Soc, 52*(8), 1326-1330.

Kramer, A. F., Colcombe, S., Erickson, K., Belopolsky, A., McAuley, E., Cohen, N. J., et al. (2002). Effects of aerobic fitness training on human cortical function: a proposal. *J Mol Neurosci, 19*(1-2), 227-231.

Kua, A., Korner-Bitensky, N., Desrosiers, J., Man-Son-Hing, M., & Marshall, S. (2007). Older driver retraining: a systematic review of evidence of effectiveness. *J Safety Res, 38*(1), 81-90.

Li, G., Braver, E., & Chen, L. (2003). Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. *Accid Anal Prev, 35*(2), 227-235.

Lyman, J. M., McGwin, G., Jr., & Sims, R. V. (2001). Factors related to driving difficulty and habits in older drivers. *Accid Anal Prev, 33*(3), 413-421.

Magill, R. (2003). *Motor Learning and control, concepts and applications* (Seventh ed.). New York: McGraw-Hill.

Manser, M. P., & Hancock, P. A. (1996). Influence of approach angle on estimates of Time to-Contact. *Ecol Psychol, 8*(1), 71-99.

Marottoli, R., Allore, H., Araujo, K., Iannone, L., Acampora, D., Gottschalk, M., et al. (2007). A randomized trial of a physical conditioning program to enhance the driving performance of older persons. *J Gern Intern Med, 22*(5), 590-597.

Marottoli, R. A., Cooney, L. M., Jr., Wagner, R., Doucette, J., & Tinetti, M. E. (1994). Predictors of automobile crashes and moving violations among elderly drivers. *Ann Intern Med, 121*(11), 842-846.

Marottoli, R. A., & Drickamer, M. A. (1993). Psychomotor mobility and the elderly driver. *Clin Geriatr Med, 9*(2), 403-411.

Marottoli, R. A., Ness, P. H., Araujo, K. L., Iannone, L. P., Acampora, D., Charpentier, P., et al. (2007). A randomized trial of an education program to enhance older driver performance. *J Gerontol A Biol Sci Med Sci, 62*(10), 1113-1119.

Matos, R., & Godinho, M. (2005). Transfer of Useful Field of Vision from Team Sports to Driving Skills in a Simulated Driving Test. In L. Dorn (Ed.), *Driver behaviour and training* (Vol. II, pp. 459-470). Hamshire: Asghate Publishing Limited.

Matos, R., & Godinho, M. (2007). *Useful field of vision and peripheral reaction time in novice drivers, transfer to a real driving situation after a perceptual-motor training program.* Paper presented at the International Conference on Road Safety and Simulation 2007, Rome, Italy.

Mayhew, D. R., Simpson, H. M., & Ferguson, S. A. (2006). Collisions involving senior drivers: high-risk conditions and locations. *Traffic Inj Prev, 7*(2), 117-124.

McGwin, G., Jr., & Brown, D. B. (1999). Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accid Anal Prev, 31*(3), 181-198.

McGwin, G., Jr., Sims, R. V., Pulley, L., & Roseman, J. M. (2000). Relations among chronic medical conditions, medications, and automobile crashes in the elderly: a population-based case-control study. *Am J Epidemiol, 152*(5), 424-431.

McKnight, A. J., & McKnight, A. S. (1999). Multivariate analysis of age-related driver ability and performance deficits. *Accid Anal Prev, 31*(5), 445-454.

Olson, P., & Dewar, R. (2007). Introduction. In R. Dewar & P. Olson (Eds.), *Human factors in traffic safety* (pp. 1-7). Tucson: Lawyers & Judges Publishing Co., Inc.

Ostrow, A. C., Shaffron, P., & McPherson, K. (1992). The effects of a joint range-of-motion physical fitness training program on the automobile driving skills of older adults. *J Safety Res, 23*, 207-219.

Owsley, C., Ball, K., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1991). Visual/cognitive correlates of vehicle accidents in older drivers. *Psychol Aging, 6*(3), 403-415.

Preusser, D. F., Williams, A. F., Ferguson, S. A., Ulmer, R. G., & Weinstein, H. B. (1998). Fatal crash risk for older drivers at intersections. *Accid Anal Prev, 30*(2), 151-159.

Recarte, M. A., & Nunes, L. M. (2003). Mental workload while driving: effects on visual search, discrimination, and decision making. *J Exp Psychol Appl, 9*(2), 119-137.

Roth, D. L., Goode, K. T., Clay, O. J., & Ball, K. K. (2003). Association of physical activity and visual attention in older adults. *J Aging Health, 15*(3), 534-547.

Sagberg, F. (2006). Driver health and crash involvement: A case-control study. *Accid Anal Prev, 38*(1), 28-34.

Salthouse, T., & Meinz, E. (1995). Aging, inhibition, working memory, and speed. *J Gerontol B Psychol Sci Soc Sci, 50B*(6), 297-306.

Shay, K. A., & Roth, D. L. (1992). Association between aerobic fitness and visuospatial performance in healthy older adults. *Psychol Aging, 7*(1), 15-24.

Sims, R. V., McGwin, G., Jr., Allman, R. M., Ball, K., & Owsley, C. (2000). Exploratory study of incident vehicle crashes among older drivers. *J Gerontol A Biol Sci Med Sci, 55*(1), M22-27.

Sims, R. V., McGwin, G., Jr., Pulley, L. V., & Roseman, J. M. (2001). Mobility impairments in crash-involved older drivers. *J Aging Health, 13*(3), 430-438.

Spirduso, W. W. (2006). Issues of aging, physical activity, cognition and putative mechanisms for a relationship: a discussion. In L. W. Poon, W. Chodzko-Zajko & P. D. Tomporowski (Eds.), *Active living, Cognitive Functioning and Aging* (pp. 187-195). Champaign: Human Kinetics.

Spirduso, W. W., Francis, K. L., & MacRae, P. G. (2005). *Physical Dimensions of Aging-2nd Edition*. Champaign, IL: Human Kinetics.

Taylor, A., & Dorn, L. (2006). Stress, fatigue, health, and risk of road traffic accidents among professional drivers: the contribution of physical inactivity. *Annu. Rev. Public Health, 27*, 371-391.

Tuokko, H., Rhodes, R., & Dean, R. (2007). Health conditions, health symptoms and driving difficulties in older adults. *Age and ageing, 36*(4), 389.

van Boxtel, M. P., Paas, F. G., Houx, P. J., Adam, J. J., Teeken, J. C., & Jolles, J. (1997). Aerobic capacity and cognitive performance in a cross-sectional aging study. *Med Sci Sports Exerc, 29*(10), 1357-1365.

Whelihan, W. M., DiCarlo, M. A., & Paul, R. H. (2005). The relationship of neuropsychological functioning to driving competence in older persons with early cognitive decline. *Arch Clin Neuropsychol, 20*(2), 217-228.

World Health Organization. The Heidelberg Guidelines for Promoting Physical Activity among Older Persons. *J Aging Phys Act, 5*, 2-8.

CHAPTER V

Effects of exercise in on-the-road driving performance

Article 5. **Exercise can improve speed of behavior in older drivers**

Article 6. **Tennis playing, but not running, can enhance speed of behavior in older drivers**

Exercise can improve speed of behavior in older drivers

José Marmeleira, Filipe Melo, Mouhaydine Tlemcani, Mário Godinho

Abstract

The main aim of this research was to study the effects of a specific exercise program on the speed of behavior of older adults during on-the road driving. Twenty-six drivers (55-78 years) were randomly assigned to either an exercise or a control group. The exercise program (3 sessions of 60 min per week for 8 weeks) incorporated tasks that induced the participants to respond quickly to challenging situations. On-the road driving tasks (under single and dual-task conditions) included measures of simple and choice reaction time, movement time, and response time. Significant positive effects were found at follow-up resulting from participation in the exercise program: improvements were found for several measures in all driving tasks and a composite score reflected a better general drivers' speed of behavior. These results show that exercise is capable of enhancing speed of behavior among older drivers and should therefore be promoted.

Key words: Automobile driving, aging, reaction time, and physical activity

The Journal of Aging and Physical Activity (2011), 19: 48-61.

INTRODUCTION

Slowing and increasing variability of motor performance during human aging is a well-demonstrated phenomenon (Der & Deary, 2006; Hultsch, MacDonald, & Dixon, 2002; Spirduso, Francis, & MacRae, 2005). The negative effect of age on reaction time (RT) is more pronounced in tasks that have high levels of complexity (Der & Deary, 2006) and could affect the way people perform daily functional tasks such as driving a car (Spirduso, et al., 2005). Research has shown that speed of behavior (i.e., RT to environmental stimuli and speed of execution) can be improved by the practice of physical activity, both in simple and choice reaction tasks (American College of Sports Medicine [ACSM], 1998; Spirduso, 2006). However, few studies have explored this potential link among older drivers.

Previous studies have established an association between speed of behavior and on-road tests (McKnight & McKnight, 1999; Odenheimer, et al., 1994) or crashes (Margolis, et al., 2002). Driving is a complex and interactive task involves a variety of skills and requires the ability to make appropriate and timely decisions. The speed at which visual information is processed may be an important factor for the successfully negotiation of difficult or dangerous traffic situations (Anstey, Wood, Lord, & Walker, 2005). The relevance of peripheral vision to driving has been noted in sub-tasks such as lane-maintenance (Land & Horwood, 1995) and hazard detection (Chapman & Underwood, 1998).

Unfortunately, it has been reported that older drivers show a significantly decreased visual attention ability reflecting a spatial constriction in the useful field of view (Ball, Beard, Roenker, Miller, & Griggs, 1988) or in the visual information processing efficiency (Sekuler, Bennett, & Mamelak, 2000). It is promising that previous studies have found positive effects of physical activity practice on the visual processing speed and divided visual attention (Marmeleira, Godinho, & Fernandes, 2009; Roth, Goode, Clay, & Ball, 2003).

Increases in RT with aging are evident when it is necessary to control attention while performing concurrent tasks. In driving, dual-task deficits have frequently been observed in older adults (Bherer, et al., 2005; Chaparro, Wood, & Carberry, 2005). Secondary tasks appear to interfere with driving, affecting the detection of hazards and changes in the driving scenery (Recarte & Nunes, 2003). Research has revealed that dual-task deficits can be reduced by either specific cognitive training (Bherer, et al., 2005) or by physical activity training (Hawkins, Kramer, & Capaldi, 1992; Marmeleira, et al., 2009).

There is now strong evidence that exercise and physical activity have a significant impact on several psychological parameters (Chodzko-Zajko, et al., 2009). Important support for this relationship comes from intervention studies. For instance, it has been shown that exercise promote greater information processing speed (Marmeleira, et al., 2009; Rikli & Edwards, 1991), enhancement of attention capacity in dual-task situations (Hawkins, et al., 1992), and better visual-attention skills (Roth, et al., 2003). Investigation has also indicated that the frontal system, a region that mediates executive function, is the primary locus in which aging-related cognitive deficits are found (West, 1996) and also the locus in which exercise appears to exert its greatest influence (Colcombe & Kramer, 2003).

It has been proposed that physical activity is associated with changes in underlying mechanisms such as cerebral blood flow (Swain, et al., 2003), cerebral structure (Colcombe, et al., 2006), brain-derived neurotrophic factor (Zoladz, et al., 2008), neurotransmitters (Meeusen, 2005), and gene expression patterns (Booth, Chakravarthy, & Spangenburg, 2002). The gains in cardiovascular fitness are frequently considered the main physiological mediator that underlies the cognitive benefits of physical activity (Chodzko-Zajko & Moore, 1994; van Boxtel, et al., 1997). Nevertheless, some studies have failed to obtain evidence for the relation between aerobic fitness and cognitive function (Colcombe & Kramer, 2003; Etnier, Nowell, Landers, & Sibley, 2006). Thus, the underlying mediators of the relationship between physical activity and cognitive performance have yet to be fully identified (Etnier, et al., 2006).

Few investigations have explored the potential link between physical training and driving-related abilities. Recent studies have shown that forms of exercise that require demanding information processing and for which the speed of behavior is crucial, could be positively transferred to driving situations (Marmeleira, et al., 2009; Matos & Godinho, 2009). However, other studies (Hancock, Kane, Scallen, & Albinson, 2002) have not found any advantage of sport practitioners in comparison with non-practitioners in a braking task experiment.

A major question is what type of exercise is more suitable to affect driving-related abilities. For instance, it seems reasonable to consider that exercise which incorporate activities that intend to enhance speed of behavior could have a higher impact on the individual's capacity to respond quickly to environmental stimuli during actual driving. This idea is supported in the hypothesis that for positive transfer to occur between training and transfer tasks they must involve the same cognitive processing demands (Magill, 2003). In addition, studies that have compared the individual and combined effects of physical and mental exercise interventions reported cognitive benefits to be greater for the combined cognitive and aerobic training paradigms (Fabre, Chamari, Mucci, Masse-Biron, & Prefaut, 2002; Oswald, Rupprecht, Gunzelmann, & Tritt, 1996).

A great deal of research has focused on elderly drivers' crash-involvement patterns, but not on the development of methods to enhance their driving-related abilities. Recently, it was reported that an exercise program developed to stress perceptive, cognitive, and physical abilities was capable of improving speed of behavior among older drivers, but measures were collected in a simulated scenario (Marmeleira, et al., 2009). In this context, the main aim of this research was to study the effects of a similar exercise program on the speed of behavior of older adults during on-the road driving.

METHODS

Participants

Participants were recruited from the local community by posted flyers and local radio/newspaper announcements. The inclusion criteria were: aged 55 years or more; live independently in the community; healthy without serious cardiovascular or musculoskeletal disease; possess a valid driving license; 0.5 or greater corrected visual acuity; and normal cognitive status on the Mini-Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975).

Twenty-six participants fulfilled the inclusion criteria; one subject was excluded due to severe osteoarthritis. Computer-generated random numbers stratified by gender were used to randomize participants to either the control group (CG) or the exercise group (EG). During the entire 8-week period, the CG continued to follow normal daily activities. At the 8-week follow-up, all adults in each research group completed the post-tests (EG, 65.5 ± 6.9 years; CG, 63.4 ± 6.7 years). The minimum and maximum ages were 55-76 years and 57-78 years in the EG and in the CG, respectively; 9 and 8 females were in the CG and EG, respectively.

Procedures

Two instrumented cars were used in the experiments: participants drove a Volkswagen Golf and a research assistant drove a Fiat Uno. In the Fiat a radio telemetry transmitter was instantly activated by the car electric circuit whenever the rear brake light was turned on; in the Volkswagen, the testing devices included a radio telemetry receiver, microswitches attached to the foot pedals and 6 light emitting diodes (LEDs). The LEDs were controlled using a laptop and an interface kit. All signs were detected by a MP100 Biopac® system (interfaced with a laptop) and treated with Acqnowledge® 3.7.2 software. The signal of the accelerator was registered when it was initially released; the signal from the brake pedal was detected when it was initially depressed.

Adjustments of seats, mirrors, and seat belts were done before getting on the road (rural road with little traffic). Participants were instructed to follow the leading car and to maintain a close but safe distance of about 30 m (the exception was the Peripheral RT Task, where the participants drove without the other research car in front). The vehicles speed was around 50 km/h. One investigator seated in the back seat in the vehicle driven by the participant ensured that the design protocols were followed, namely that the sequence and time intervals between stimuli (minimum of 5 s and maximum of 16 s) were identical for all participants and that the required distance to the leading car was maintained. Participants were instructed to detect stimuli as fast as possible while keeping their attention on without withdrawing their attention from the road. The same investigator and research assistant conducted both the pre- and post-assessments. The Institutional Human Research Ethics Committee approved this study.

Brake RT task

Participants were instructed to brake as quickly as possible whenever the leading car's rear brake lights were activated. The total drive time was about 6 min. The participant had to respond to 26 onsets of the rear brake lights (2 for practice and 24 for data acquisition). Three time measures (ms) were recorded: (i) RT, measured from the onset of the leading car brake lights to the initial release of the accelerator by the driver participant; (ii) movement time, the period from the initial release of the accelerator to the initial brake application; and (iii) response time, measured from the onset of the leading car brake lights to the initial brake application.

Peripheral RT task

Six red LEDs were positioned on the car's windshields (5 in the front and 1 in the left windshield). In order to cover both sides of the field of view, the LEDs were placed approximately at 10º, 20º and 30º left (3 LEDs) and right (3 LEDs) of the centre of the sight line of the driver and approximately 8º elevated above the car console. The LEDs have a light intensity of 10.0 cd.

The participants reacted by depressing a microswitch with their left thumb that was attached to the left side of the steering wheel. One LED at a time was illuminated during 2 s (fewer time if the microswitch was depressed). The total time of the task was about 8 min. The participant had to respond to 54 onsets of the LEDs (6 for practice and 48 – 8 by LED – for data acquisition). Performance was recorded in the form of number of signal misses and RTs in milliseconds (ms).

This type of task has been used before and depends greatly on divided visual attention (Wood, 2002), which is a skill frequently associated with driving performance in the elderly population (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Wood, 2002).

Choice RT task

A two-choice task was used. The participants were instructed to follow the leading car and to react as quickly as possible to the stimuli: (i) the leading car rear brake lights were activated and (ii) one of two LEDs placed in the front windshield (20º left and right) were activated. In the first condition, the participant should brake; in the second condition, the participant should depress the microswitch attached to the steering wheel with their left thumb. The utilization of two LEDs instead of one intended to target both sides of the visual field and to avoid any posture adjustments of the driver to position the LEDs in a more central region of his/her visual field.

The total time of the task was about 6 min during which the participant had to respond to 32 stimuli (4 for practice and 28 for data acquisition). The occurrence of each stimulus type was balanced. Performance was evaluated by the RTs (ms) and number of errors.

Dual-task condition

The primary task was similar to the brake RT task (i.e., the participant had to brake as fast as possible whenever the leading car rear brake lights were activated). The time intervals between the stimulus onsets were also the same as for the brake RT task. For the secondary task, a mental calculation task was used which required participants to verbally report the result of sum or subtraction of pairs of numbers presented by the researcher. A new pair of numbers was presented roughly every 5 s. This type of secondary task has been used frequently (Chaparro, et al., 2005; Marmeleira, et al., 2009). Performance measurements were similar to those of the brake RT task. It was previously demonstrated that drivers' ability is negatively influenced by the interference resulting from performing non-visual task whilst driving (Lamble, Kauranen, Laakso, & Summala, 1999). Dual-task paradigms have also commonly been used to investigate executive functioning (Adcock, Constable, Gore, & Goldman-Rakic, 2000).

Exercise intervention

The EG participated in a supervised exercise program 3 days a week for 8 weeks. Each session lasted approximately 60 min. The exercise intervention incorporated physical tasks that induced the participants to respond to challenging situations by producing the desirable motor responses. The idea was that physical activities that make large cognitive demands may influence some aspects of cognition more than repetitive and cyclic activities (Spirduso, 2006).

The type of tasks incorporated in the intervention were very similar to those used in another study (Marmeleira, et al., 2009). However, more emphasis was placed on activities that intend to enhance the participants' speed of behavior; frequently, the time needed to respond was a criterion of success. Some examples of the types of activities are: tasks that target simple RT (e.g., while walking, an auditory/visual sign is presented that implies a specific psychomotor response); tasks that focused choice RT (e.g., similar to the simple RT but including more then one auditory/visual sign); dual-task situations (e.g., walking in different directions while executing another motor task with the arms); activities that work peripheral vision (e.g., maintaining several balloons in the air); activities focused on response inhibition (e.g., while maintaining balloons in the air, all auditory numeric signs except one require rapidly catching specific colored balloons); actions that required planning efforts and decision making (e.g., orienteering in the gymnasium and in an open space); activities strongly depending on working memory (e.g., selecting and completing a specific walking course in the gymnasium after the presentation of the associated auditory signal; auditory cues-walking courses correspondence were previously established). Cooperative games requiring a dynamic group behavior were frequently included.

It is important to emphasize that the intervention in this study could not be considered multimodal in the common view of a program with two distinct parts (mental exercise and physical exercise) that are implemented side-by-side with the goal of improving cognitive function in older adults. The type of program that this research advocates is clearly a physical exercise program, where cognitively challenging tasks are executed by the older adults employing physical activities like walking, stepping, reaching, throwing, and manipulating objects.

Statistical analyses

The upper bound of each time component measurement was established by computing the mean and standard deviation separately for each participant (CG and EG, baseline and after 8 weeks) and dropping any trial exceeding the mean by three or more standard deviations (Hultsch, et al., 2002). A lower bound for legitimate responses was set at 150 ms, and scores below this limit were dropped. To capture the overall driving performance for each participant compared with the whole group, a composite driving score was computed for the baseline and follow-up by standardizing each of the RT measures (calculating z scores) from the four road tests and summing z scores. In order to show the main effect of time the composite driving score at follow-up was calculated using the mean and standard deviation from the baseline RT measures.

Data normality was evaluated by the Shapiro-Wilk Test. An independent sample *t*-test was used to study differences at baseline between the CG and the EG. The paired sample *t*-test was used to compare data within each group at baseline and after 8 weeks. To assess whether the exercise and control groups showed differential change after 8 weeks, analyses of covariance (ANCOVAs) were conducted on the change scores (i.e., post-intervention minus baseline), with baseline score serving as the covariate. Effect sizes are reported as partial eta squared (η_p^2) with cut-off values of .01, .06, and .14 for small, medium and large effects, respectively (Cohen, 1988). The results are expressed as means (SD). Significance was set at $p < .05$ for all tests. Data were analyzed using SPSS 15.0 for Windows (SPSS, Chicago, IL).

RESULTS

The general groups' characteristics (Table 1) were similar in gender, age, visual acuity, MMSE score, years with driving licence and weekly physical activity as measured by the International Physical Activity Questionnaire-Short Form (Craig, et al., 2003). Six participants from each group practiced some type of exercise (mainly dance or aquatic exercise) for at least 1 year. Compliance in the exercise sessions was very good, exceeding 80% for all participants.

Table 1. General sample characteristics

	Control Group	Exercise Group	*p*
N	13	13	
Female, Male	8, 5	9, 4	.680
Age (years)	63.4 (6.7)	65.5 (6.9)	.514
Visual Acuity (decimal)	1.1 (0.2)	1.1 (0.3)	.905
MMSE (points)	28.7 (1.2)	28.9 (1.1)	.731
IPAQ-Short (MET min week^{-1})	1576 (1182)	1759 (1194)	.698
Weekly distance driven (km)	80.1 (47.6)	86.4 (52.0)	.741
Time with driving licence (years)	36.0 (5.5)	30.5 (12.2)	.183

Note. IPAQ, International Physical Activity Questionnaire-Short Form; MMSE, Mini-Mental State Examination

At baseline, the EG and CG did not show any statistical difference in the driving-related variables. However, several within and between group differences were found after 8 weeks (Table 2).

In the brake RT task, significant improvements were found among the EG in RT (−8%; p = .008) and response time (−7%; p = .045) after 8 weeks. Inter-group analysis indicated significant differences in the 8-week changes between groups for RT (−8% for the EG and 3% for the CG): F (1, 24) = 6.91, p = .015, η_p^2 = .231.

In the peripheral RT task, significant improvements were found within the EG (−8%; p = .045) after 8 weeks. In the choice RT task, significant improvements were found among the EG in RT (−7%; p = .018) at follow-up. Inter-group analysis indicated significant differences in the 8-week changes between groups (−7% for the EG and 1% for the CG): F (1, 24) = 10.32, p = .004, η_p^2 = .310.

In the dual-task condition, inter-group analysis indicated significant differences in the 8-week changes between groups for response time (−7% for the EG and 1% for the CG): F (1, 24) = 5.08, p = .034, η_p^2 = .181.

The EG displayed significant differences compared with the CG for the magnitude of the improvement on the composite score from the pre- to post-test measures (p = .002; η_p^2 = .358; Figure 1).

Table 2. Driving measurements at baseline and at 8 weeks

Variables	Baseline Mean (SD)	8-weeks Mean (SD)	Difference Between Means Mean (95% CI)	p †
Brake RT Task				
RT (ms)				
CG	421.2 (64.4)	431.8 (34.2)	10.6 (-26.6, 47.8)	.015
EG	438.4 (73.5)	401.7 (56.4)	-36.7 (-62.0, -11.4) *	
Movement Time (ms)				
CG	284.1 (53.4)	283.5 (48.6)	-0.5 (-19.6, 18.9)	.583
EG	306.4 (41.0)	287.5 (55.3)	-18.9 (-53.7, 15.9)	
Response Time (ms)				
CG	707.3 (91.6)	714.6 (71.8)	7.2 (-31.5, 46.0)	.083
EG	740.5 (100.5)	686.4 (107.3)	-54.1 (-105.4, -2,6) *	
Peripheral RT Task				
RT (ms)				
CG	446.6 (95.2)	434.8 (96.4)	-11.8 (-63.3, 39.6)	.167
EG	415.7 (82.5)	381.9 (56.8)	-33.8 (-66.6, -0.93) *	
Undetected LEDs				
CG	1.6 (1.9)	1.2 (1.6)	-0.5 (-1.83, 0.90)	.763
EG	1.3 (1.1)	1.5 (1.2)	0.2 (-0.49, 0.80)	
Choice RT Task				
RT (ms)				
CG	597.1 (68.2)	601.7 (67.7)	4.6 (-43.0, 52.3)	.004
EG	560.1 (89.3)	519.1 (53.4)	-41.0 (-73.5, -8.5) *	
Errors				
CG	2.4 (1.3)	2.3 (1.4)	-0.08 (-0.91, 0.76)	.187
EG	3.1 (1.7)	3.3 (1.4)	0.2 (-0.43, 0.89)	
Dual Task				
RT (ms)				
CG	607.9 150.7)	615.5 (79.2)	7.6 (-65.3, 80.5)	.059
EG	622.4 (173.3)	577.2 (86.2)	-45.2 (-110.6, 20.3)	
Movement Time (ms)				
CG	285.8 (59.3)	292.0 (47.4)	6.2 (-11.4, 23.9)	.264
EG	316.6 (40.9)	296.9 (49.3)	-19.7 (-46.2, 6.8)	
Response Time (ms)				
CG	890.9 (189.6)	917.4 (126.8)	26.5 (-47.1, 100.1)	.034
EG	941.8 (200.6)	872.1 (100.3)	-69.7 (-154.7, 15.3)	

Note. Abbreviation: CI, confidence interval.
* $p < 0.05$ changes within the group. Paired sample *t*-test.
† *p* values for differences in the 8-week changes between groups. Analysis of covariance (ANCOVA).

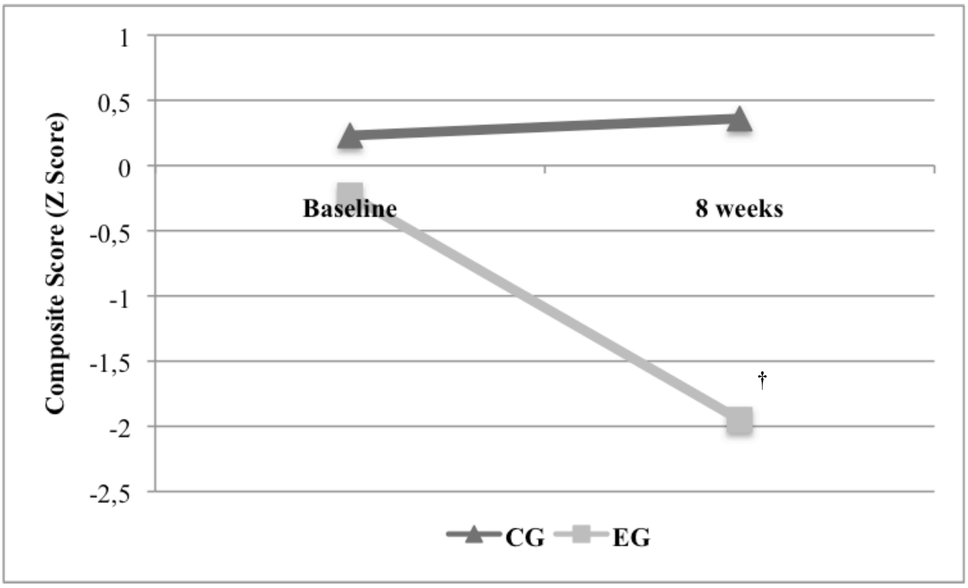


Figure 1. Composite driving scores for the CG and the EG at baseline and 8-week follow-up. † $p < .01$ for differences in the 8-week changes between groups. Analysis of covariance (ANCOVA). Lower composite scores indicate greater speed of behavior

DISCUSSION

This study is one of the few to investigate the effects of exercise in the speed of behavior of older drivers. During the training program, task constraints induced the participants to increase the speed of central mental processes (e.g., stimulus identification, response selection, and response programming) in order to accomplish the desired responses. Significant positive effects occurred in the simple, two-choice and peripheral RT tasks and in the dual-task condition. Moreover, a composite score reflecting all RT measurements also showed significant improvements.

The need to quickly choose between different motor responses according to the stimuli presented was recurrently trained in the exercise sessions, extending the findings of a previous study in the choice-RT task (Marmeleira, et al., 2009). Considering that driving is carried out in changeable environments, choice RT paradigms seem particularly important in the assessment of driving-related abilities. A higher association of on-road driving performance with a complex rather than with a simple RT paradigm has been previously reported (Odenheimer, et al., 1994).

The peripheral RT task performance showed small benefits from the exercise program. Some previous studies have reported that the time to react to peripheral stimuli is amenable to improvement by the practice of sports or perceptive-motor programs (Ando, Kida, & Oda, 2001) while others fail to demonstrate such an effect (Helsen & Starkes, 1999). In the driving-related literature, there are reports of positive effects of cognitive speed of processing training on visual attention paradigms that involve the presentation of simultaneous stimuli in both central and peripheral vision (Ball, Edwards, & Ross, 2007; Roenker, Cissell, Ball, Wadley, & Edwards, 2003). However, it is important to note that these studies were conducted in laboratory settings and did not measure response time but only response accuracy. It is expectable that, when measurements are carried out during actual driving, some performance decrement in peripheral reaction time may occur as a result of a probable increase in anxiety which leads to the allocation of more attentional resources to the central driving task (Janelle, 2002).

The present study did not find significant differences in the changes between groups along the 8-week period in the peripheral RT task. However, considering the significant improvement within the EG, it seems realistic to expect larger inter-group differences if the exercise program had been extended in time. It is important to note that during the intervention program, several activities were planned to focus specifically on peripheral vision; nevertheless, it is difficult to isolate their particular contribution to the peripheral RT task performance because previous research has shown that the practice on visual stimulus in the central vision can shortened the RT to stimulus in the peripheral vision, and *vice versa* (Ando, Kida, & Oda, 2002).

The dual-task condition reflected significant effects of the training program, reinforcing previous findings that improvements in attention performance resulting from dual-task training is generalizable to new task combinations involving new stimuli (Bherer, et al., 2008; Marmeleira, et al., 2009). These results are very promising considering that dual-task deficits are frequently observed in older adults. Secondary tasks interfere with driving, affecting the detection of hazards and changes in the driving scene (Recarte & Nunes, 2003). A recent study demonstrated that performing mental calculations while driving markedly increased the average reaction time of elderly drivers in comparison with younger drivers (Makishita & Matsunaga, 2008). Driving leads to a greater mental workload for older drivers than for younger drivers, and this effect is exacerbated by more complex driving contexts (Cantin, Lavalliere, Simoneau, & Teasdale, 2009).

The generalized learning achieved from the exercise program to the on-the road driving tests reinforces previous findings about the potential of exercise and perceptual-motor training in promoting important driving-related abilities (Marmeleira, et al., 2009; Matos & Godinho, 2009). This is a very positive outcome given that motor learning frequently show a great specificity with little generalization to related tasks or new environments (for an overview see Green)(Green & Bavelier, 2008).

There have been some reports of a positive transfer from cognitive speed of processing training to driving behavior among older adults (Edwards, et al., 2009; Roenker, et al., 2003). In these studies, speed training was mainly administered on computer screens, focusing the ability to identify visual information quickly in a central or divided-attention format. In the present study, we used physical exercise as the training strategy and emphasis was placed not only in stimulus perception but also in adjusted and quicker motor responses.

Much research has been focused on the effects of aerobic fitness on measures of cognitive function (ACSM, 1998); however, there is a lack of studies concerning the hypothesis that physical activities exerting large cognitive demands may have an important influence on cognition (Spirduso, 2006). In addition, some meta-analysis did not support the cardiovascular fitness hypothesis, which suggests that physical activity is capable of enhancing cognitive functioning only when aerobic fitness is improved (Colcombe & Kramer, 2003; Etnier, et al., 2006). Thus, it is possible that mechanisms other than aerobic fitness may mediate changes in cognitive functioning obtainable through physical activity. Following this line of thought, special emphasis was given in the present study to the type of activities included in the exercise program. An important idea was to stimulate psychological mechanisms that promote transfer of learning from the exercise program to the driving tasks. The design of the exercise program was supported in the hypothesis that positive transfer of learning occurs primarily because of similarities between the amount and types of cognitive processes required by the performance situations (Magill, 2003).

Speed of behavior was successfully enhanced using a challenging form of exercise that simultaneously required physical effort (e.g., aerobic capacity and range-of-motion) and mental effort (e.g., speed of processing, visual attention and dual-task processing). Larger effect sizes were found in all tasks with the exception of the peripheral RT task. The fact that marked improvements occurred in a sample where about 50% of the participants were already engaged in exercise strengthens the idea that the perceptive and cognitive specificity of the program was fundamental. It is important to note that previous research has found that combined physical and cognitive training produced greater improvements in cognitive function than either physical or cognitive training alone (Fabre, et al., 2002). Future studies should continue to examine this issue.

At follow-up, the composite score reflected a better general drivers' speed of behavior. Improvement of information processing speed is especially promising for its potential to impact older adults' functional abilities that maintain independence and quality of life (Edwards, et al., 2005; Owsley, Sloane, McGwin, & Ball, 2002). For instance, Ball et al. (2007) examined data from six studies that used the same computer-based speed of processing training program, and concluded that participants maintained benefits of training for at least 2 years, which translated not only to safer driving performance but also to efficient performance of other instrumental activities of daily living. The relevance of the results from the present study is also consubstantiate on the theory that changes in cognitive function with age can result from generalized, age-related slowing of processing speed (Birren & Fisher, 1995).

The present study has some limitations, and caution should be taken in generalizing the findings. A relatively small sample of drivers participated and evaluations were conducted in open-road driving, but drivers were aware of the stimulus-response correspondence. Also, possible bias might have been introduced in the study due to the fact that the investigator involved in the assessments was not blinded for the participants group and because the control group did not receive any control intervention. Finally, it was not possible to differentiate between contributions to the obtained improvements by specific characteristics of the exercise program and possible training effects of physical fitness (physical fitness was not measured).

Future research using longitudinal designs is needed to examine whether change in behavioral speed promoted by the exercise program can prevent motor vehicle crashes among older drivers.

CONCLUSION

The present research showed that the speed of behavior of older drivers could be improved through exercise. Therefore, training interventions for older drivers should integrate exercise programs. Furthermore, if exercise programs for older adults incorporate activities that stimulate both perceptive and cognitive abilities, the greatest functional benefits could be achieved.

REFERENCES

Adcock, R. A., Constable, R. T., Gore, J. C., & Goldman-Rakic, P. S. (2000). Functional neuroanatomy of executive processes involved in dual-task performance. *Proc Natl Acad Sci U S A, 97*(7), 3567-3572.

American College of Sports Medicine (2008). Position Stand: Exercise and physical activity for older adults. *Med Sci Sports Exerc, 30*(6), 992-1008.

Ando, S., Kida, N., & Oda, S. (2001). Central and peripheral visual reaction time of soccer players and nonathletes. *Percept Mot Skills, 92*(3 Pt 1), 786-794.

Ando, S., Kida, N., & Oda, S. (2002). Practice effects on reaction time for peripheral and central visual fields. *Percept Mot Skills, 95*(3 Pt 1), 747-751.

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clin Psychol Rev, 25*(1), 45-65.

Ball, K., Edwards, J. D., & Ross, L. A. (2007). The impact of speed of processing training on cognitive and everyday functions. *J Gerontol B Psychol Sci Soc Sci, 62 Spec No 1*, 19-31.

Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Invest Ophthalmol Vis Sci, 34*(11), 3110-3123.

Ball, K., Beard, B. L., Roenker, D. L., Miller, R. L., & Griggs, D. S. (1988). Age and visual search: expanding the useful field of view. *J Opt Soc Am A, 5*(12), 2210-2219.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: are there age-related differences in plasticity of attentional control? *Psychol Aging, 20*(4), 695-709.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: further evidence for cognitive plasticity in attentional control in late adulthood. *Exp Aging Res, 34*(3), 188-219.

Birren, J. E., & Fisher, L. M. (1995). Aging and speed of behavior: possible consequences for psychological functioning. *Annu Rev Psychol, 46*, 329-353.

Booth, F. W., Chakravarthy, M. V., & Spangenburg, E. E. (2002). Exercise and gene expression: physiological regulation of the human genome through physical activity. *J Physiol, 543*(Pt 2), 399-411.

Cantin, V., Lavalliere, M., Simoneau, M., & Teasdale, N. (2009). Mental workload when driving in a simulator: effects of age and driving complexity. *Accid Anal Prev, 41*(4), 763-771.

Chaparro, A., Wood, J. M., & Carberry, T. (2005). Effects of age and auditory and visual dual tasks on closed-road driving performance. *Optom Vis Sci, 82*(8), 747-754.

Chapman, P. R., & Underwood, G. (1998). Visual search of driving situations: danger and experience. *Perception, 27*(8), 951-964.

Chodzko-Zajko, W. J., & Moore, K. A. (1994). Physical fitness and cognitive functioning in aging. *Exerc Sport Sci Rev, 22*, 195-220.

Chodzko-Zajko, W. J., Proctor, D. N., Fiatarone Singh, M. A., Minson, C. T., Nigg, C. R., Salem, G. J., et al. (2009). American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc, 41*(7), 1510-1530.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum.

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci, 14*(2), 125-130.

Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R., McAuley, E., et al. (2006). Aerobic exercise training increases brain volume in aging humans. *J Gerontol A Biol Sci Med Sci, 61*(11), 1166-1170.

Craig, C. L., Marshall, A. L., Sjostrom, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., et al. (2003). International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc, 35*(8), 1381-1395.

Der, G., & Deary, I. J. (2006). Age and sex differences in reaction time in adulthood: results from the United Kingdom Health and Lifestyle Survey. *Psychol Aging, 21*(1), 62-73.

Edwards, J. D., Myers, C., Ross, L. A., Roenker, D. L., Cissell, G. M., McLaughlin, A. M., et al. (2009). The longitudinal impact of cognitive speed of processing training on driving mobility. *Gerontologist, 49*(4), 485-494.

Edwards, J. D., Wadley, V. G., Vance, D. E., Wood, K., Roenker, D. L., & Ball, K. K. (2005). The impact of speed of processing training on cognitive and everyday performance. *Aging Ment Health, 9*(3), 262-271.

Etnier, J., Nowell, P., Landers, D., & Sibley, B. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research Reviews, 52*(1), 119-130.

Fabre, C., Chamari, K., Mucci, P., Masse-Biron, J., & Prefaut, C. (2002). Improvement of cognitive function by mental and/or individualized aerobic training in healthy elderly subjects. *Int J Sports Med, 23*(6), 415-421.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res, 12*(3), 189-198.

Green, C. S., & Bavelier, D. (2008). Exercising your brain: a review of human brain plasticity and training-induced learning. *Psychol Aging, 23*(4), 692-701.

Hancock, P. A., Kane, M. J., Scallen, S., & Albinson, C. B. (2002). Effects of gender and athletic participation on driving capability. *Int J Occup Saf Ergon, 8*(2), 281-292.

Hawkins, H. L., Kramer, A. F., & Capaldi, D. (1992). Aging, exercise, and attention. *Psychol Aging, 7*(4), 643-653.

Helsen, W., & Starkes, J. (1999). A multidimensional approach to skilled perception and performance in sport. *Appl Cogn Psychol, 13*(1), 1-27.

Hultsch, D. F., MacDonald, S. W., & Dixon, R. A. (2002). Variability in reaction time performance of younger and older adults. *J Gerontol B Psychol Sci Soc Sci, 57*(2), P101-115.

Janelle, C. M. (2002). Anxiety, arousal and visual attention: a mechanistic account of performance variability. *J Sports Sci, 20*(3), 237-251.

Lamble, D., Kauranen, T., Laakso, M., & Summala, H. (1999). Cognitive load and detection thresholds in car following situations: safety implications for using mobile (cellular) telephones while driving. *Accid Anal Prev, 31*(6), 617-623.

Land, M., & Horwood, J. (1995). Which parts of the road guide steering? *Nature, 377*(6547), 339-340.

Magill, R. (2003). *Motor Learning and control, concepts and applications* (Seventh ed.). New York: McGraw-Hill.

Makishita, H., & Matsunaga, K. (2008). Differences of drivers' reaction times according to age and mental workload. *Accid Anal Prev, 40*(2), 567-575.

Margolis, K. L., Kerani, R. P., McGovern, P., Songer, T., Cauley, J. A., & Ensrud, K. E. (2002). Risk factors for motor vehicle crashes in older women. *J Gerontol A Biol Sci Med Sci, 57*(3), M186-191.

Marmeleira, J. F., Godinho, M. B., & Fernandes, O. M. (2009). The effects of an exercise program on several abilities associated with driving performance in older adults. *Accid Anal Prev, 41*(1), 90-97.

Matos, R., & Godinho, M. (2009). Useful field of vision and peripheral reaction time in novice drivers: transfer to a real driving situation after a perceptual-motor training program. *Adv Transp Stud An Int J, 19*, 77-84.

McKnight, A. J., & McKnight, A. S. (1999). Multivariate analysis of age-related driver ability and performance deficits. *Accid Anal Prev, 31*(5), 445-454.

Meeusen, R. (2005). Exercise and the brain: insight in new therapeutic modalities. *Ann Transplant, 10*(4), 49-51.

Odenheimer, G. L., Beaudet, M., Jette, A. M., Albert, M. S., Grande, L., & Minaker, K. L. (1994). Performance-based driving evaluation of the elderly driver: safety, reliability, and validity. *J Gerontol, 49*(4), M153-159.

Oswald, W. D., Rupprecht, R., Gunzelmann, T., & Tritt, K. (1996). The SIMA-project: effects of 1 year cognitive and psychomotor training on cognitive abilities of the elderly. *Behav Brain Res, 78*(1), 67-72.

Owsley, C., Sloane, M., McGwin, G., & Ball, K. (2002). Timed instrumental activities of daily living tasks: Relationship to cognitive function and everyday performance assessments in older adults. *Gerontology, 48*, 254-265.

Recarte, M. A., & Nunes, L. M. (2003). Mental workload while driving: effects on visual search, discrimination, and decision making. *J Exp Psychol Appl, 9*(2), 119-137.

Rikli, R. E., & Edwards, D. J. (1991). Effects of a three-year exercise program on motor function and cognitive processing speed in older women. *Res Q Exerc Sport, 62*(1), 61-67.

Roenker, D. L., Cissell, G. M., Ball, K. K., Wadley, V. G., & Edwards, J. D. (2003). Speed-of-processing and driving simulator training result in improved driving performance. *Hum Factors, 45*(2), 218-233.

Roth, D. L., Goode, K. T., Clay, O. J., & Ball, K. K. (2003). Association of physical activity and visual attention in older adults. *J Aging Health, 15*(3), 534-547.

Sekuler, A. B., Bennett, P. J., & Mamelak, M. (2000). Effects of aging on the useful field of view. *Exp Aging Res, 26*(2), 103-120.

Spirduso, W. W. (2006). Issues of aging, physical activity, cognition and putative mechanisms for a relationship: a discussion. In L. W. Poon, W. Chodzko-Zajko & P.

D. Tomporowski (Eds.), *Active living, Cognitive Functioning and Aging* (pp. 187-195). Champaign: Human Kinetics.

Spirduso, W. W., Francis, K. L., & MacRae, P. G. (2005). *Physical Dimensions of Aging-2nd Edition*. Champaign, IL: Human Kinetics.

Swain, R. A., Harris, A. B., Wiener, E. C., Dutka, M. V., Morris, H. D., Theien, B. E., et al. (2003). Prolonged exercise induces angiogenesis and increases cerebral blood volume in primary motor cortex of the rat. *Neuroscience, 117*(4), 1037-1046.

van Boxtel, M. P., Paas, F. G., Houx, P. J., Adam, J. J., Teeken, J. C., & Jolles, J. (1997). Aerobic capacity and cognitive performance in a cross-sectional aging study. *Med Sci Sports Exerc, 29*(10), 1357-1365.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychol Bull, 120*(2), 272-292.

Wood, J. M. (2002). Age and visual impairment decrease driving performance as measured on a closed-road circuit. *Hum Factors, 44*(3), 482-494.

Zoladz, J. A., Pilc, A., Majerczak, J., Grandys, M., Zapart-Bukowska, J., & Duda, K. (2008). Endurance training increases plasma brain-derived neurotrophic factor concentration in young healthy men. *J Physiol Pharmacol, 59 Suppl 7*, 119-132.

Tennis playing, but not running, can enhance speed of behavior in older drivers

José Marmeleira, Filipe Melo, Mouhaydine Tlemcani,
Mário Godinho, Jorge Fernandes

Abstract

The main aim of this study was to examine the effects of tennis playing and running in the speed of behavior of older drivers. Thirty-six male active drivers with ages between 55 and 76 years (63.2 ± 6.0 years) participated in this study. A battery of four on-the road driving tests was performed by tennis players, runners, and a control group (not engaged in sports). Measures of simple and choice reaction time (RT), movement time, and response time were collected under single- and dual-task conditions. A composite driving score resulting from the RT measures of all driving tests was calculated to reflect a general drivers' speed of behavior. One-way ANOVA and post-hoc Scheffé tests were used to analyze differences between groups. Significant differences between groups were found in a driving braking task for simple RT (p=0.026), movement time (p=0.047) and response time (p=0.017). Post hoc analysis showed that tennis players performed significantly better than controls in simple RT (p=0.035) and response time (p=0.037). The composite score was also significantly different between groups (p=0.036), with the post-hoc tests revealing that tennis players have better results than controls (p=0.035). A clear trend toward a hierarchy of performance was found in the majority of measurements with tennis players showing the best results, followed by runners and then controls. Regular participation in tennis is capable of enhancing speed of behavior in older drivers. Thus, sports that are strongly dependent on the speed of information processing could have a positive influence on the ability of older adults to respond quickly during driving events.

Keywords: driving, aging, sports, reaction time

Submitted

INTRODUCTION

Driving is a complex and interactive task that involves a variety of skills and requires the ability to make appropriate and timely decisions. For example, the speed at which visual information is processed is an important factor for the successfully negotiation of difficult or dangerous traffic situations (Anstey, Wood, Lord, & Walker, 2005). It is known that detrimental effects of aging on reaction time (RT) are pronounced in tasks that have high levels of complexity (Der & Deary, 2006) and could affect the way people perform daily functional tasks such as driving a car (Spirduso, Francis, & MacRae, 2005).

Slowing and increasing variability of motor performance during human aging is a well-demonstrated phenomenon (Der & Deary, 2006; Hultsch, MacDonald, & Dixon, 2002; Spirduso, et al., 2005). Fortunately, research has shown that speed of behavior (i.e., RT to environmental stimuli and speed of execution) can be improved by the practice of PA, both in simple and choice reaction tasks (American College of Sports Medicine, 1998; Spirduso, 2006). Speed of behavior is associated with the performance in on-road tests (McKnight & McKnight, 1999; Odenheimer, et al., 1994) or crashes (Margolis, et al., 2002).

With advancing aging, there is a decline in several motor, perceptive and cognitive abilities that have a negative impact in driving performance. Many older adults depend greatly on their personal vehicle for transportation and suffer a marked loss of quality of life when, as a consequence of no longer being able or allowed to drive, their mobility becomes significantly restricted (Marmeleira, Godinho, & Vogelaere, 2009). Unfortunately, statistical data show that older drivers have a high crash rate per distance travelled (Guerrier, Manivannan, & Nair, 1999; Lyman, Ferguson, Braver, & Williams, 2002; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998) and an increased risk of injury or death in the event of a traffic crash (Li, Braver, & Chen, 2003; McGwin, Sims, Pulley, & Roseman, 2000).

Older adults' long-term participation in sports is of particular interest when examining the role of exercise in preventing age-related decrements in physical and cognitive functioning. In this context, it is of interest to examine whether sport participation results in superior driving performance. Tennis and running are two popular sports among older adults, and previous investigation has reported benefits resulting from their practice. In one of the first studies that compared cognitive functioning between the physically fit and physically unfit older adults, Spirduso & Clifford (1978) evaluated young and old racquet sportsmen, runners, and sedentary individuals on simple, choice, and movement time tasks. The older athletes' performance was significantly better than that of the older sedentary adults and was comparable to the performance of the young sedentary adults. According to a recent literature review, veteran tennis playing was associated with improvements in aerobic capability, strength, and RT performance (Marks, 2006). Running has been cited to have positive effects on aerobic capacity (Rogers, Hagberg, Martin, Ehsani, & Holloszy, 1990) and general health (Fries, et al., 1994).

The scientific interest in the relations between active living, cognitive functioning and aging has grown in the last years. It has been proposed that physical activity is associated with changes in the underlying mechanisms responsible for better cognitive functioning, such as cerebral blood flow (Swain, et al., 2003), cerebral structure (Colcombe, et al., 2006), brain-derived neurotrophic factor (Zoladz, et al., 2008), neurotransmitters (Meeusen, 2005), and gene expression patterns (Booth, Chakravarthy, & Spangenburg, 2002). The gains in cardiovascular fitness are frequently considered the main physiological mediator that underlies the cognitive benefits of PA (Chodzko-Zajko & Moore, 1994; van Boxtel, et al., 1997). Despite the growing body of evidence on the benefits of physical activity for cognitive functioning in older adults, few studies have investigated its potential repercussions for the performance of activities of daily living (most research has been focused on the effects of PA in neuropsychological tests scores). In the present study, the possible benefits of PA in aging are investigated in an instrumental activity of daily living during an on-road driving protocol.

Another purpose of this investigation is to examine if different types of sports have distinctive effects on the speed of behavior. In our view, it seems reasonable to hypothesize that sports that repeatedly require speed of behavior have a greater impact on the individual's capacity to respond quickly to environmental stimuli during driving. This idea is based on the hypothesis that for positive transfer to occur between training and transfer tasks, they must involve the same cognitive processing demands (Magill, 2003). According to a recent meta-analysis (Voss, Kramer, Basak, Prakash, & Roberts, 2009), the type of sport influences some cognitive outcomes as athletes from interceptive-dominant sports (e.g. squash, tennis) had faster response times than athletes from a sport category that included closed, self-paced sports (e.g., golf and swimming).

One of the few studies that have investigated the possible link between sports and driving (Hancock, Kane, Scallen, & Albinson, 2002) has not found better performance in the sport practitioners compared with non-practitioners in a braking task experiment. However, recent studies have shown that programs of exercise that require demanding information processing and for which the speed of behavior is crucial, could be positively transferred to driving situations in novices and older drivers (Marmeleira, Godinho, & Fernandes, 2009; Marmeleira, Melo, Godinho, & Tlemecani, in press; Matos & Godinho, 2009). It is also important to note that previous studies reported a positive transfer from cognitive speed of processing training to driving behavior among older adults (Edwards, et al., 2009; Roenker, Cissell, Ball, Wadley, & Edwards, 2003). In these studies, the training protocol was applied in computer screens focusing on the ability to identify visual information quickly in a central, divided or selective-attention format. Team- and interceptive-sports seem to share some of these visual attention requirements. In addition, when compared with the computer-based speed of processing training programs, sports require an extra feature that is also frequently solicited in driving: fast motor responses.

Tennis and long distance running are two appealing types of sports to study the associations between sports practice and driving-related abilities because they have different demands in perceptive and cognitive skills. Actually, on one side both are physiologically stressful and can positively influence physical fitness (Marks, 2006; Rogers, et al., 1990), and on the other side, tennis is obviously more challenging in attentional and decisional skills (mental processes that are also crucial to driving). Thus, it could be that years of running or tennis influences the major mechanisms (e.g., enhanced cerebral blood flow) considered to underlie improvements in cognitive performance with physical activity; however, due to great similarities with the mental resources required in tennis, driving performance could benefit more from this sport than from running.

To the best of our knowledge, no study has investigated the influence of regular sport practice in the driving-related abilities of older adults. In this context, the main aim of this research was to examine the effects of two types of sports, namely tennis and running, on the speed of behavior of older adults in on-the road driving tasks. Furthermore, this study also intends to investigate whether tennis and running are associated with different levels of driving performance as a result of their different cognitive processing demands.

METHOD

Participants

Thirty-six male active drivers of ages between 55 and 76 years (63.2 ± 6.0 years) recruited among community-dwelling older adults participated in this study. Drivers from the control group (n=12) were contacted personally in recreational associations; those from the long distance running (n=12) and tennis groups (n=12) were contacted personally through sports associations. Questionnaires were administered to gather information on demographic variables, physical activity practice, driving habits, functional impairments, and medical conditions.

General inclusion criteria for all participants were: aged 55 years or more; living independently in the community; healthy without serious cardiovascular or musculoskeletal disease; possess a valid driving license; 20/40 or greater corrected binocular vision measured with a Snellen Chart; normal cognitive status on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975). Drivers in the control group could not be engaged in any exercise program for at least 1 year; an exercise program was defined as any type of PA that is planned and structured, occurring at least 1 day per week. Runners and tennis players were engaged in these sports at least 2 times per week for the last 10 years.

Procedures

The data were collected using similar instrumentation and procedures described in Marmeleira, Melo, Godinho and Tlemecani (in press). Two instrumented cars were used in the experiments: participants drove a Volkswagen Golf and a research assistant drove a Fiat Uno. In the Fiat a radio telemetry transmitter was instantly activated by the car electric circuit whenever the rear brake light was turned on; in the Volkswagen, the testing devices included a radio telemetry receiver, microswitches attached to the foot pedals and 6 light emitting diodes (LEDs). The

LEDs were controlled using a laptop and an interface kit. All signs were detected by a MP100 Biopac® system (interfaced with a laptop) and treated with Acqnowledge® 3.7.2 software. The signal of the accelerator was registered when it was initially released; the signal from the brake pedal was detected when it was initially depressed.

Adjustments of seats, mirrors, and seat belts were done before getting on the road (rural road with little traffic). Participants were instructed to follow the leading car and to maintain a close but safe distance of about 30 m (the exception was the Peripheral RT Task, where the participants drove without the other research car in front). The vehicles speed was around 50 km/h. One investigator seated in the back seat in the vehicle driven by the participant ensured that the design protocols were followed, namely that the sequence and time intervals between stimuli (minimum of 5 s and maximum of 16 s) were identical for all participants and that the required distance to the leading car was maintained. Participants were instructed to detect stimuli as fast as possible while keeping their attention on without withdrawing their attention from the road. The same investigator and research assistant conducted the assessments. The Institutional Human Research Ethics Committee approved this study.

Brake RT task

Participants were instructed to brake as quickly as possible whenever the leading car's rear brake lights were activated. The total drive time was about 6 min. The participant had to respond to 26 onsets of the rear brake lights (2 for practice and 24 for data acquisition). Three time measures (ms) were recorded: (i) RT, measured from the onset of the leading car brake lights to the initial release of the accelerator by the driver participant; (ii) movement time, the period from the initial release of the accelerator to the initial brake application; and (iii) response time, measured from the onset of the leading car brake lights to the initial brake application.

Peripheral RT task

Six red LEDs were positioned on the car's windshields (5 in the front and 1 in the left windshield). In order to cover both sides of the field of view, the LEDs were placed approximately at 10º, 20º and 30º left (3 LEDs) and right (3 LEDs) of the centre of the sight line of the driver and approximately 8º elevated above the car console. The LEDs have a light intensity of 10.0 cd.

The participants reacted by depressing a microswitch with their left thumb that was attached to the left side of the steering wheel. One LED at a time was illuminated during 2 s (fewer time if the microswitch was depressed). The total time of the task was about 8 min. The participant had to respond to 54 onsets of the LEDs (6 for practice and 48 – 8 by LED – for data acquisition). Performance was recorded in the form of number of signal misses and RTs in milliseconds (ms).

This type of task has been used before and depends greatly on divided visual attention (Wood, 2002), which is a skill frequently associated with driving performance in the elderly population (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Wood, 2002).

Choice RT task

A two-choice task was used. The participants were instructed to follow the leading car and to react as quickly as possible to the stimuli: (i) the leading car rear brake lights were activated and (ii) one of two LEDs placed in the front windshield (20º left and right) were activated. In the first condition, the participant should brake; in the second condition, the participant should depress the microswitch attached to the steering wheel with their left thumb. The utilization of two LEDs instead of one intended to target both sides of the visual field and to avoid any posture adjustments of the driver to position the LEDs in a more central region of his/her visual field.

The total time of the task was about 6 min during which the participant had to respond to 32 stimuli (4 for practice and 28 for data acquisition). The occurrence of each stimulus type was balanced. Performance was evaluated by the RTs (ms) and number of errors.

Dual-task condition

The primary task was similar to the brake RT task (i.e., the participant had to brake as fast as possible whenever the leading car rear brake lights were activated). The time intervals between the stimulus onsets were also the same as for the brake RT task. For the secondary task, a mental calculation task was used which required participants to verbally report the result of sum or subtraction of pairs of numbers presented by the researcher. A new pair of numbers was presented roughly every 5 s. This type of secondary task has been used frequently (Chaparro, Wood, & Carberry, 2005; Marmeleira, Godinho, & Fernandes, 2009). Performance measurements were similar to those of the brake RT task. It was previously demonstrated that drivers' ability is negatively influenced by the interference resulting from performing non-visual task whilst driving (Lamble, Kauranen, Laakso, & Summala, 1999). Dual-task paradigms have also commonly been used to investigate executive functioning (Adcock, Constable, Gore, & Goldman-Rakic, 2000).

Data Analysis

The upper bound of each time component measurement was established by computing the mean and standard deviation separately for each participant and dropping any trial exceeding the mean by three or more standard deviations (Hultsch, et al., 2002; Marmeleira, Melo, Tlemcani, & Godinho, in press). A lower bound for legitimate responses was set at 150 ms, and scores below this limit were dropped. To capture the overall driving performance for each participant compared with the whole group, a composite driving score was computed by standardizing each of the RT measures (calculating z scores) from the four road tests and summing z scores

Data normality was evaluated by the Shapiro-Wilk Test. Between-group comparisons of data were analyzed using one-way ANOVA and Scheffe's F test or independent *t*-tests where appropriate. The results are expressed as means (SD). Significance was set at $p < 0.05$ for all tests. Data were analyzed using SPSS 17.0 for Windows (SPSS, Chicago, IL).

RESULTS

The general characteristics of the groups and the main results from the comparison of driving performance are presented in Table 1. The groups' characteristics were similar in age, education, visual acuity and driving habits. Runners trained more frequently than tennis players and participated in more competitions.

Differences between groups were found in the brake RT task for RT, movement time and response time. Post hoc analysis revealed that the tennis players had better RT (*p*=0.035) and response time (*p*=0.037) than the control group.

Despite the lack of statistical significance, the tennis players had better results than the other groups in all time measurements, and runners were better than controls for almost all time measurements (the Peripheral RT task was the exception). This trend was most evident for both the Choice RT task and the Dual-Task condition, with levels of significance falling short of reaching statistical differences.

Finally, the composite score, a general measure of speed performance, displayed significant differences between groups, with post hoc tests showing that the tennis players had a significantly better performance than the control group (*p*=0.035). Once more, despite the lack of statistical significance (*p*=0.123), the composite score showed that runners had also a better performance than controls.

Table 1. General sample characteristics and driving measurements for each group

	A Control	B Runners	C Tennis players	*p**	Sheffé
Total (N=36)	12	12	12		
Age (yrs)	64.1 (6.3)	62.7 (5.7)	62.8 (6.4)	0.828	-
Education (yrs)	9.8 (4.2)	8.3 (3.0)	10.4 (4.3)	0.380	-
Visual acuity (decimal)	1.03 (0.2)	1.07 (0.2)	1.1 (0.2)	0.407	-
Time with driving licence (yrs)	37.4 (6.7)	37.3 (6.7)	41.3 (8.8)	0.339	-
Weekly distance driven (km)	275.8 (162.4)	235.8 (189.2)	382.5 (149.8)	0.102	-
Sports practice (yrs)	-	23.8 (8.2)	30.8 (8.2)	0.097	-
Training sessions week (N.)	-	4.8 (1.3)	2.4 (1.2)	0.001	-
Competitions year (N.)	-	10.0 (4.7)	5.4 (3.6)	0.013	-
Brake RT task					
RT (ms)	397.8 (62.3)	344.6 (74.0)	329.3 (44.9)	0.026	A>C
Movement time (ms)	235.7 (55.7)	226.1 (40.6)	193.7 (20.8)	0.047	-
Response time (ms)	636.0 (108.2)	570.7 (103.3)	523.0 (50.5)	0.017	A>C
Peripheral RT task					
RT (ms)	376.1 (68.0)	397.2 (80.0)	342.6 (66.0)	0.186	-
Choice RT task					
RT (ms)	546.8 (68.6)	537.50 (102.6)	477.4 (64.2)	0.086	-
Number of errors	3.2 (1.95)	4.3 (2.0)	3.4 (1.4)	0.316	-
Dual-task condition					
RT (ms)	562.8 (151.1)	508.0 (134.8)	449.2 (56.6)	0.087	-
Movement time (ms)	241.7 (56.5)	230.6 (39.8)	203.8 (27.8)	0.097	-
Response time (ms)	806.4 (202.5)	740.6 (164.4)	650.6 (64.5)	0.061	-
Composite Score (Z-score)	1.42 (3.17)	0.37 (3.28)	-1.79 (2.01)	0.031	A>C

Note. *Independent sample *t*-test or One-way Anova. RT = reaction time.

DISCUSSION

This study intended to investigate the effect of sports practice in the speed of behavior of older drivers. Driving performance was evaluated in four on-the road driving tests that target two forms of RT (simple and choice), different interference conditions (single and dual-task paradigms) and different parts of the field of vision (central and peripheral). The results showed that older drivers engaged in tennis practice took less time to react to stimuli during driving compared with those that are not engaged in sports activities. The difference between these two groups of drivers was statistically significant in the brake RT task and, and even more relevant in the composite driving score. Runners have also a higher level of performance compared with their peers that do not participate in sports, although statistical significance was not reached. As has been hypothesized, a trend was found in favor of tennis players over runners on several measures of behavioral speed. To our knowledge, this is the first time that a positive transfer effect from a sport to driving performance has been demonstrated in older adults.

A trend toward a different performance between groups was found in all driving tasks, although a statistically significance difference was established only for the brake RT task (better performance for tennis players than controls). It was interesting that significant differences between the groups were found for simple but not for choice RT, considering that the common belief among the scientific community is that exercise exerts a higher influence on the latter. However, the available data does not seem to support this idea. Hall, Smith and Keele (2001) reviewed studies that have employed RT measurements and reported that there is no consistent evidence from cross-sectional studies that exercise improves choice RT more than simple RT. The authors cited the seminal study of Spirduso (1975) to demonstrate that the results were contrary to expectation because both aging and physical activity had greater effects on simple than choice RT. The cross-sectional study of Clarkson-Smith & Hartley (1989) is one of the few to report that choice RT benefits more from exercise than simple RT. Among interventional studies, some contradictory findings have also been reported. Rikli and Edwards (1991) presented some evidence that exercise improves choice RT more than simple RT, while other studies failed to find such effect (e.g., Dustman, et al., 1984). Recently, an experimental study (Marmeleira, Melo, Tlemcani, et al., in press) examined the effects of an exercise program in the speed of behavior of older drivers using the same assessment protocol as in the present study. The authors reported improvements with larger effects for both simple and choice RT after 8 weeks. In their study, the type of intervention was unlike the traditional programs in that the exercises were planned to be more focused on specific cognitive abilities considered relevant (e.g., information processing speed and divided visual attention) for the driving task. Emphasis was placed on the activities that were intended to enhance the participants' speed of behavior and frequently the time needed to respond was a criterion of success.

The present study showed that the regular participation in sports had a positive influence on the performance of an instrumental activity of daily living. In the domain of sports psychology, some studies have also demonstrated that skill changes associated with sports practice are transferable to specific cognitive abilities. For example, Ando, Kida & Oda (2001) reported that soccer players showed shorter premotor times during central and peripheral visual RT tasks than nonathletes. Improvements in visual attention were also shown in young volleyball players (Castiello & Umiltá, 1992) and older orienteering experts (Pesce, Cereatti, Casella, Baldari, & Capranica, 2007). Nevertheless, other studies have failed to find differences between experts and nonexpert athletes on cognitive measures (Lum, Enns, & Pratt, 2002; McAuliffe, 2004). For example, Helsen & Starkes (1999) have not found advantages for semi-professional soccer on various nonspecific abilities that include processing speed (e.g., peripheral RT).

As hypothesized, the type of sport had a significant influence on driving performance. Little research to date has explored the idea that different types of exercise might have different effects on cognitive functioning. This is probably due to the frequent focus on physical fitness as the primary mediator in the relationship between PA and cognitive functioning (e.g., Chodzko-Zajko & Moore, 1994). The findings of the present study were consistent with those that did not support the *cardiovascular fitness hypothesis* (Colcombe & Kramer, 2003; Panton, Graves, Pollock, Hagberg, & Chen, 1990). Thus, is does not seem reasonable to infer that the physiological demands of tennis playing on the cardiovascular system were higher than those from running (moreover, runners trained more frequently and for more years than tennis players) and thereby led to best performances for the tennis practitioners group.

The present results support the hypothesis that exercises that make large cognitive demands may influence cognitive functioning more than repetitive and cyclic activities (Spirduso, 2006). Hence, although it seems reasonable to consider that both tennis and running are associated with good physical fitness, tennis is clearly more dependent on attentional, decisional and problem-solving skills, involving information processing under time pressure (Marks, 2006). This potential differential effect according to the type of sport is supported by a recent meta-analysis (Voss, et al., 2009) as interceptive sport types (e.g., squash, tennis) had the largest effects on measures of processing speed and attention (e.g., divided attention) than closed, self-paced sports (e.g., golf and swimming). In summary, the similarity between the amount and types of cognitive processes required by tennis playing and the driving tasks is probably an important foundation for the positive transfer of learning that was found (please see Magill, 2003).

Investigations conducted in animal models have also shown that the type of exercise stimulation has specific neuroanatomic influences. It was reported that exercise characterized by unskilled motor movements increased capillary density without significant change in synapse number, whereas motor skill learning induced synaptogenesis in higher-order brain regions involved in motor learning with no change in capillary density (Black, Isaacs, Anderson, Alcantara, & Greenough, 1990; Kleim, Lussnig, Schwarz, Comery, & Greenough, 1996). Recent studies reported that significantly higher gray matter tissue density in some brain areas was observed for competitive judo players compared with a group of healthy controls (Jacini, et al., 2009) and that Tai-Chi may elicit long-term plasticity in primary sensory cortical maps (Kerr, et al., 2008). Taken together, these findings strongly suggest that the brain is remarkably plastic in response to experience both structurally and functionally. Future research should examine whether older adults also show plastic changes in the brain as a result of their continued engagement in sports.

The present study has some limitations that should be taken into account when interpreting the findings. A cross-sectional design was used, and thus, it is difficult to establish cause-effects relations. Evaluations were conducted in open-road driving, but the drivers were aware of the stimulus-response correspondence. Additionally, aerobic fitness was not measured, and this made it impossible to compare groups on a capacity that is traditionally associated with cognitive functioning. Finally, it is important that future research using longitudinal designs examine whether the speed of behavior promoted by tennis playing can actually prolong driving independence and even prevent motor vehicle crashes among older drivers.

In summary, this study showed that tennis playing benefited the driving-related speed of behavior of older drivers. Moreover, despite the lack of statistical significance, a trend was found in favor of running practitioners compared with the group of drivers that did not practice sports on several measures of behavioral speed. Considering that the changes in cognitive function with age can result from generalized age-related slowing of information processing speed (Birren & Fisher, 1995), the improvement of this ability may have an important impact in older adults' driving ability and in other functional abilities.

REFERENCES

Adcock, R. A., Constable, R. T., Gore, J. C., & Goldman-Rakic, P. S. (2000). Functional neuroanatomy of executive processes involved in dual-task performance. *Proc Natl Acad Sci U S A, 97*(7), 3567-3572.

American College of Sports Medicine (2008). Position Stand: Exercise and physical activity for older adults. *Med Sci Sports Exerc, 30*(6), 992-1008.

Ando, S., Kida, N., & Oda, S. (2001). Central and peripheral visual reaction time of soccer players and nonathletes. *Percept Mot Skills, 92*(3 Pt 1), 786-794.

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clin Psychol Rev, 25*(1), 45-65.

Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Invest Ophthalmol Vis Sci, 34*(11), 3110-3123.

Birren, J. E., & Fisher, L. M. (1995). Aging and speed of behavior: possible consequences for psychological functioning. *Annu Rev Psychol, 46*, 329-353.

Black, J. E., Isaacs, K. R., Anderson, B. J., Alcantara, A. A., & Greenough, W. T. (1990). Learning causes synaptogenesis, whereas motor activity causes angiogenesis, in cerebellar cortex of adult rats. *Proc Natl Acad Sci U S A, 87*(14), 5568-5572.

Booth, F. W., Chakravarthy, M. V., & Spangenburg, E. E. (2002). Exercise and gene expression: physiological regulation of the human genome through physical activity. *J Physiol, 543*(Pt 2), 399-411.

Castiello, U., & Umiltá, C. (1992). Orienting of attention in volleyball players. *Int J Sport Psychol, 23*(4), 301-310.

Chaparro, A., Wood, J. M., & Carberry, T. (2005). Effects of age and auditory and visual dual tasks on closed-road driving performance. *Optom Vis Sci, 82*(8), 747-754.

Chodzko-Zajko, W. J., & Moore, K. A. (1994). Physical fitness and cognitive functioning in aging. *Exerc Sport Sci Rev, 22*, 195-220.

Clarkson-Smith, L., & Hartley, A. A. (1989). Relationships between physical exercise and cognitive abilities in older adults. *Psychol Aging, 4*(2), 183-189.

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci, 14*(2), 125-130.

Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R., McAuley, E., et al. (2006). Aerobic exercise training increases brain volume in aging humans. *J Gerontol A Biol Sci Med Sci, 61*(11), 1166-1170.

Der, G., & Deary, I. J. (2006). Age and sex differences in reaction time in adulthood: results from the United Kingdom Health and Lifestyle Survey. *Psychol Aging, 21*(1), 62-73.

Dustman, R. E., Ruhling, R. O., Russell, E. M., Shearer, D. E., Bonekat, H. W., Shigeoka, J. W., et al. (1984). Aerobic exercise training and improved neuropsychological function of older individuals. *Neurobiol Aging, 5*(1), 35-42.

Edwards, J. D., Myers, C., Ross, L. A., Roenker, D. L., Cissell, G. M., McLaughlin, A. M., et al. (2009). The longitudinal impact of cognitive speed of processing training on driving mobility. *Gerontologist, 49*(4), 485-494.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res, 12*(3), 189-198.

Fries, J. F., Singh, G., Morfeld, D., Hubert, H. B., Lane, N. E., & Brown, B. W., Jr. (1994). Running and the development of disability with age. *Ann Intern Med, 121*(7), 502-509.

Guerrier, J. H., Manivannan, P., & Nair, S. N. (1999). The role of working memory, field dependence, visual search, and reaction time in the left turn performance of older female drivers. *Appl Ergon, 30*(2), 109-119.

Hall, C., Smith, A., & Keele, S. (2001). The impact of aerobic activity on cognitive function in older adults: A new synthesis based on the concept of executive control. *Eur J Cogn Psychol, 13*(1), 279-300.

Hancock, P. A., Kane, M. J., Scallen, S., & Albinson, C. B. (2002). Effects of gender and athletic participation on driving capability. *Int J Occup Saf Ergon, 8*(2), 281-292.

Helsen, W., & Starkes, J. (1999). A multidimensional approach to skilled perception and performance in sport. *Appl Cogn Psychol, 13*(1), 1-27.

Hultsch, D. F., MacDonald, S. W., & Dixon, R. A. (2002). Variability in reaction time performance of younger and older adults. *J Gerontol B Psychol Sci Soc Sci, 57*(2), P101-115.

Jacini, W. F., Cannonieri, G. C., Fernandes, P. T., Bonilha, L., Cendes, F., & Li, L. M. (2009). Can exercise shape your brain? Cortical differences associated with judo practice. *J Sci Med Sport, 12*(6), 688-690.

Kerr, C. E., Shaw, J. R., Wasserman, R. H., Chen, V. W., Kanojia, A., Bayer, T., et al. (2008). Tactile acuity in experienced Tai Chi practitioners: evidence for use dependent plasticity as an effect of sensory-attentional training. *Exp Brain Res, 188*(2), 317-322.

Kleim, J. A., Lussnig, E., Schwarz, E. R., Comery, T. A., & Greenough, W. T. (1996). Synaptogenesis and Fos expression in the motor cortex of the adult rat after motor skill learning. *J Neurosci, 16*(14), 4529-4535.

Lamble, D., Kauranen, T., Laakso, M., & Summala, H. (1999). Cognitive load and detection thresholds in car following situations: safety implications for using mobile (cellular) telephones while driving. *Accid Anal Prev, 31*(6), 617-623.

Li, G., Braver, E. R., & Chen, L. H. (2003). Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. *Accid Anal Prev, 35*(2), 227-235.

Lum, J., Enns, J. T., & Pratt, J. (2002). Visual orienting in college athletes: explorations of athlete type and gender. *Res Q Exerc Sport, 73*(2), 156-167.

Lyman, S., Ferguson, S. A., Braver, E. R., & Williams, A. F. (2002). Older driver involvements in police reported crashes and fatal crashes: trends and projections. *Inj Prev, 8*(2), 116-120.

Magill, R. (2003). *Motor Learning and control, concepts and applications* (Seventh ed.). New York: McGraw-Hill.

Margolis, K. L., Kerani, R. P., McGovern, P., Songer, T., Cauley, J. A., & Ensrud, K. E. (2002). Risk factors for motor vehicle crashes in older women. *J Gerontol A Biol Sci Med Sci, 57*(3), M186-191.

Marks, B. L. (2006). Health benefits for veteran (senior) tennis players. *Br J Sports Med, 40*(5), 469-476; discussion 476.

Marmeleira, J., Godinho, M., & Fernandes, O. (2009). The effects of an exercise program on several abilities associated with driving performance in older adults. *Accid Anal Prev, 41*(1), 90-97.

Marmeleira, J., Godinho, M., & Vogelaere, P. (2009). The potential role of physical activity on driving performance and safety among older adults. *European Review of Aging and Physical Activity, 6*(1), 29-38.

Marmeleira, J., Melo, F., Tlemcani, M., & Godinho, M. (in press). Exercise can improve speed of behavior in older adults. *J Aging Phys Act*.

Matos, R., & Godinho, M. (2009). Useful field of vision and peripheral reaction time in novice drivers: transfer to a real driving situation after a perceptual-motor training program. *Advances in Transportation Studies: An International Journal., 19*, 77-84.

McAuliffe, J. (2004). Differences in attentional set between athletes and nonathletes. *J Gen Psychol, 131*(4), 426-437.

McGwin, G., Jr., Sims, R. V., Pulley, L., & Roseman, J. M. (2000). Relations among chronic medical conditions, medications, and automobile crashes in the elderly: a population-based case-control study. *Am J Epidemiol, 152*(5), 424-431.

McKnight, A. J., & McKnight, A. S. (1999). Multivariate analysis of age-related driver ability and performance deficits. *Accid Anal Prev, 31*(5), 445-454.

Meeusen, R. (2005). Exercise and the brain: insight in new therapeutic modalities. *Ann Transplant, 10*(4), 49-51.

Odenheimer, G. L., Beaudet, M., Jette, A. M., Albert, M. S., Grande, L., & Minaker, K. L. (1994). Performance-based driving evaluation of the elderly driver: safety, reliability, and validity. *J Gerontol, 49*(4), M153-159.

Panton, L. B., Graves, J. E., Pollock, M. L., Hagberg, J. M., & Chen, W. (1990). Effects of aerobic and resistance training on fractioned reaction time and speed of movement. *J Gerontol: Medical Sciences, 45*, M26-31.

Pesce, C., Cereatti, L., Casella, R., Baldari, C., & Capranica, L. (2007). Preservation of visual attention in older expert orienteers at rest and under physical effort. *J Sport Exerc Psychol, 29*(1), 78-99.

Preusser, D. F., Williams, A. F., Ferguson, S. A., Ulmer, R. G., & Weinstein, H. B. (1998). Fatal crash risk for older drivers at intersections. *Accid Anal Prev, 30*(2), 151-159.

Rikli, R. E., & Edwards, D. J. (1991). Effects of a three-year exercise program on motor function and cognitive processing speed in older women. *Res Q Exerc Sport, 62*(1), 61-67.

Roenker, D. L., Cissell, G. M., Ball, K. K., Wadley, V. G., & Edwards, J. D. (2003). Speed-of-processing and driving simulator training result in improved driving performance. *Hum Factors, 45*(2), 218-233.

Rogers, M. A., Hagberg, J. M., Martin, W. H., 3rd, Ehsani, A. A., & Holloszy, J. O. (1990). Decline in VO2max with aging in master athletes and sedentary men. *J Appl Physiol, 68*(5), 2195-2199.

Spirduso, W. (1975). Reaction and movement time as a function of age and physical activity level. *J Gerontol, 30*(4), 435.

Spirduso, W. W. (2006). Issues of aging, physical activity, cognition and putative mechanisms for a relationship: a discussion. In L. W. Poon, W. Chodzko-Zajko & P. D. Tomporowski (Eds.), *Active living, Cognitive Functioning and Aging* (pp. 187-195). Champaign: Human Kinetics.

Spirduso, W. W., & Clifford, P. (1978). Replication of age and physical activity effects on reaction and movement time. *J Gerontol, 33*(1), 26-30.

Spirduso, W. W., Francis, K. L., & MacRae, P. G. (2005). *Physical Dimensions of Aging-2nd Edition*. Champaign, IL: Human Kinetics.

Swain, R. A., Harris, A. B., Wiener, E. C., Dutka, M. V., Morris, H. D., Theien, B. E., et al. (2003). Prolonged exercise induces angiogenesis and increases cerebral blood volume in primary motor cortex of the rat. *Neuroscience, 117*(4), 1037-1046.

van Boxtel, M. P., Paas, F. G., Houx, P. J., Adam, J. J., Teeken, J. C., & Jolles, J. (1997). Aerobic capacity and cognitive performance in a cross-sectional aging study. *Med Sci Sports Exerc, 29*(10), 1357-1365.

Voss, M., Kramer, A., Basak, C., Prakash, R., & Roberts, B. (2009). Are expert athletes expert in the cognitive laboratory? A meta-analytic review of cognition and sport expertise. *Appl Cogn Psychol, 24*(6), 812-826.

Wood, J. M. (2002). Age and visual impairment decrease driving performance as measured on a closed-road circuit. *Hum Factors, 44*(3), 482-494.

Zoladz, J. A., Pilc, A., Majerczak, J., Grandys, M., Zapart-Bukowska, J., & Duda, K. (2008). Endurance training increases plasma brain-derived neurotrophic factor concentration in young healthy men. *J Physiol Pharmacol, 59 Suppl 7*, 119-132.

CHAPTER VI

General Discussion

The primary aim of the research presented in this thesis was to study the association between PA and driving ability in older drivers. In this context, several studies were conducted to relate the research on PA effects in older adults' functional capacity and the research related with driving.

In this chapter, the results are discussed more generally. More specifically, the implications of the findings are considered with respect to the justification of this thesis, to the effects of aging on driving-related abilities, to the application of interventions aimed to improve driving performance in later life, to the associations between PA and cognitive functioning, and to the orientation of future research in this area.

Main findings

The presentation of the experimental work conducted in the context of the thesis started in *Chapter 3* with a study of associations between the PA habits of a group of older drivers and diverse driving-related cognitive abilities. Physical activity was considered in terms of volume (a metabolic unit of analysis was used - MET min week^{-1}); at this point of the thesis, the level of PA was the main factor studied in its relation with driving. The rationale of this study originated primarily from the associations between PA and cognitive functioning addressed in *Chapter 1*. It was found that a higher amount of PA is associated with better scores in two specific tests of visual attention: processing speed and divided attention. After converting individual test scores to standard scores (z scores) and calculating composite scores per cognitive ability, statistical analysis revealed that higher levels of PA are significantly associated with better scores on visual attention and almost significantly associated with executive functioning. Correlations between levels of PA and general cognitive performance also fell short of reaching statistical significance.

The hypothesis that PA in older adults is positively linked with cognitive skills that have been associated with driving was partially confirmed. It is noteworthy that these positive associations were detected regardless of the limited variability of the participants' PA habits (only 11% were classified as insufficient active). It is possible that stronger associations would be observed if more participants with lower PA scores were included. The results are in line with a growing body of evidence showing that PA may have an important role on the attenuation of age-related declines in brain function and health (e.g., Etnier, 2008; Kramer, Colcombe, McAuley, Scalf, & Erickson, 2005).

Perhaps the major finding from the first field study was the significant association of higher levels of PA with better performance in the subtest 2 of UFOV® (divided attention). To the best of our knowledge, this is the first study to show such a relationship in a sample of older drivers. The moderate correlation found was important because visual attention has been frequently associated with driving performance in older adults, and the divided attention subtest of UFOV® has been demonstrated as the most powerful in predicting driving crashes (e.g., Ball, et al., 2006; Vance, et al., 2006).

The correlation (weak but of borderline statistical significance) between PA and executive functioning was consistent with the growing evidence that the frontal neural system (region that mediates executive function) benefit from physical fitness (Colcombe & Kramer, 2003; Kramer, et al., 2003). This potential effect of PA is very relevant given that this brain region is characterized by marked age-related cognitive deficits (Bixby, et al., 2007; West, 1996). The relevance of executive function for performing activities of daily living surpasses driving to a large extent. It has been shown that impaired executive function predicts declines in gait speed (Atkinson, et al., 2007), is independently associated with poor performance in lower extremity tasks that require high attentional demand (Ble, et al., 2005), and predicts physical functional declines (Carlson, et al., 1999) and mortality in elderly women (Johnson, Lui, & Yaffe, 2007).

Considering the relevance of visual attention (Owsley, et al., 1998; Whelihan, DiCarlo, & Paul, 2005) and speed perception in driving (Manser & Hancock, 1996), the next step was the examination of the effects of age on both variables. Young (18-30 years), middle-aged (38-50 years) and old driver groups (60-75 years) participated in an observational study that involved 96 subjects. The inclusion of a middle-age group was a strength of this study compared with previous driving studies (many studies focused their research on older adults or just compared them with young adults), and it made it easier to understand the evolution of abilities across the lifespan. It was demonstrated that visual attention (measured with the UFOV®) is much more sensitive to the effects of age than speed perception (measured using a TTA paradigm). Older drivers had significantly lower performance in divided and selective attention than both the young and middle-age drivers; however, the effects of age were minimal in the estimation of TTA. The results of this comparative study strengthened the idea that intervention programs must be designed to enhance visual attention in older drivers or to prevent its decrements in middle-aged drivers. The following studies in the thesis sought to respond to this challenge.

In summary, *Chapter 3* started with the demonstration of a positive association between visual attention and PA among older drivers, and ended by presenting strong data in showing the detrimental effects of age in visual attention. This launched the fundamental part of the experimental work contained in the thesis that was presented in *Chapters 4* and *5*.

The study presented in *Chapter 4* was the first to use an experimental design. It is important to highlight the relevance of this type of studies. The vast majority of research has focused on the effects of age in driving ability or on the elderly drivers' crash-involvement patterns. Studies with a focus on the development and evaluation of methods that allow for the enhancement of elderly drivers' abilities have been scarce (Kua, Korner-Bitensky, Desrosiers, Man-Son-Hing, & Marshall, 2007). To the best of our knowledge, the study presented in *Chapter 4* was one of the first to examine the effects of an exercise program on abilities associated with driving performance in older adults. The exercise program was purposely created in the context of this thesis and was characterized by the inclusion of physically and mentally challenging types of motor tasks. The theoretical background for this study was supported by three basic ideas expressed in *Chapter 1*. First, a broad range of perceptual, cognitive and physical abilities as well as health conditions is associated with driving outcomes (crashes, driving difficulties or driving exposure) (Anstey, Wood, Lord, & Walker, 2005; Vance, et al., 2006). Second, PA might be one of a few effective strategies that have the potential to improve older drivers capability, given that its potential to target several driving-related abilities has been demonstrated (Etnier, Nowell, Landers, & Sibley, 2006; Kramer, et al., 2003; Spirduso, 2006). Third, there are data from human and animal research that brain function and structure benefits from the engagement in complex tasks (c.f., “the use it or lose it hypothesis” and “enriched environmental paradigms”) (Hultsch, Hertzog, Small, & Dixon, 1999; Salthouse, 2006; Swaab, et al., 2002). *Chapter 2* included a description of the exercise program used in the experimental studies (exercise examples were given).

The results reported in *Chapter 4* confirmed several of the hypothesized effects of exercise in driving-related abilities. Hence, behavioral speed improvements were found in reaction time, movement time, and response time (both in single- and dual-task conditions); visual attention improvements were evident in speed processing and divided attention; performance improvements occurred in lower limb mobility. Previous evidence of a positive role of exercise in driving was lacking; this study showed that exercise was a suitable training strategy in driving because it was capable of enhancing several abilities relevant for driving performance and safety in older adults.

To investigate the association between exercise and driving in more representative scenarios, an on-the road driving protocol was developed. The methodology of the two studies presented in *Chapter 5* required that participants drive a car in public roads while they performed several tasks designed to collect data on speed of behavior variables. This information was carefully described in *Chapter 2*. It is important to emphasize that the measures of behavioral speed (RT to environmental stimuli and movement time) were collected during tasks requiring diverse cognitive abilities (e.g., visual attention, multi-task processing and information processing speed) that have been associated with driving performance in older adults. It is also important to point out that the use of real car driving in the driving-related research is not the norm but the exception. Technological and safety issues frequently constrain researchers to use laboratory assessments of driving capabilities (e.g., driving simulators). For the research presented in *Chapter 5*, two cars were equipped with technical instrumentation. Almost 100 tests were conducted (approximately 3000 km of driving). The driving tasks included measures of simple and choice RT, movement time, and response time, involved the use of different parts of the visual field and single and dual-task conditions. Once more, the results provided strong evidence on the beneficial role of exercise in driving; furthermore, it was shown that a particular mode of exercise might produce specific cognitive effects.

In the first study presented in *Chapter 5*, the effects of a specific exercise program on the speed of behavior of older drivers were examined using an experimental design. The type of tasks incorporated in the 8-week exercise program was very similar to that used in the experimental study presented in *Chapter 4*. However, more emphasis was placed on activities that intend to enhance the participants' speed of behavior. Significant positive effects occurred in the simple, two-choice and peripheral RT tasks and in the dual-task condition. Most important, a composite score reflecting all RT measurements also showed significant improvements. To the best of our knowledge, this study was the first one to demonstrate that exercise can improve driving performance measures that are strongly dependent on visual attention, information processing speed and multi-task processing. Other intervention studies targeting speed variables have also shown positive effects on driving, but have used computer-based programs. It has been reported that a type of speed of processing training has resulted in fewer dangerous maneuvers during open-road driving (Roenker, Cissell, Ball, Wadley, & Edwards, 2003) and delayed driving cessation in older drivers with speed of processing difficulty (Edwards, Delahunt, & Mahncke, 2009). It is important to point out that an advantage of exercise interventions for older drivers compared with cognitive training methods is that it also promotes physical fitness and general health due to its influence on numerous physiological mechanisms.

The main research question in the last study conducted in this dissertation was whether the regular practice of different forms of exercise has distinct effects on driving performance in older adults. Thus, the comparative study in *Chapter 5* examined the practice effects of two specific sport activities - long-distance running and tennis playing - on the speed of behavior of older drivers. The first activity is characterized by cyclical and closed motor skills; the second one includes more complex and open motor skills and relies to a great extent on attentional-decisional skills. It is important to point out that the participants presented a considerable experience on running or tennis practice (two to three decades). The results showed that, in general, tennis players processed information faster during driving than older adults not engaged in sports. Moreover, there was a clear tendency in the majority of the outcomes of a hierarchy of performance with tennis players showing the best results, followed by runners and then controls.

If this study had been the only one to show a positive link between exercise and cognitive functioning, one could consider that its cross-sectional design was the main responsible for the findings (i.e., it may be that healthier psychological functioning predisposes individuals toward exercise). However, taken together with the cause-effect relations between exercise and cognitive abilities that were established in the intervention studies, these results give important support to a core hypothesis of the thesis: physical exercise that make strong perceptive and cognitive demands have the potential to influence more some aspects of cognitive functioning than repetitive and cyclic motor activities as more mechanisms associated with brain function could be mobilized. Furthermore, it seems that the specific nature of the exercise produces its own specific responses and adaptations in terms of perceptual and cognitive processes. These changes promoted by exercise are probably the basis of the gains achieved in performance situations as driving.

In both studies included in *Chapter 5*, speed of behavior was considered as an umbrella concept, which was evaluated in several driving tasks that had in common the need to react and/or move quickly. These tasks were designed to mobilize cognitive abilities like visual attention or multi-task processing. The positive effects of exercise on the speed of behavior are very relevant for driving but also for other tasks of daily living. In fact, improvement of information processing speed is especially promising for its potential to impact older adults' functional abilities that maintain independence and quality of life (Edwards, et al., 2005; Owsley, Sloane, McGwin, & Ball, 2002).

Implications for interventions aimed to improve driving ability in older adults

As mentioned above, little research has focused on the development and evaluation of methods for the enhancement of driving-related abilities in older adults. Resources have been directed to characterize elderly drivers' crash-involvement patterns and to diagnose deficits in abilities necessary for driving (e.g., Anstey, et al., 2005; Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Marottoli, Cooney, Wagner, Doucette, & Tinetti, 1994).

A difficulty in programming effective training interventions for older drivers arises from the fact that the task of driving involves a complex interaction of factors. However, some training programs directed to influence specific factors like visual attention, physical mobility, and driving education have improved the driving performance of older drivers (Kooijman, et al., 2004; Marottoli, et al., 2007; Ostrow, Shaffron, & McPherson, 1992). A major point here is that much of the investigations about training programs define their target groups based on inclusion criteria that imply the presence at baseline of physical or perceptive impairments. Until now, of the interventions directed toward older drivers' capabilities in which PA represents the main strategy, the focus has been on specific abilities related to range of motion and mobility, especially in populations with physical impairments. The research presented in this thesis showed that exercise is a good candidate for positively impacting several driving-related abilities in older drivers that do not belong to any clinical groups in particular. Thus, visual attention, information processing speed, executive functioning, and lower limb mobility can be improved by the practice of PA. The findings of this thesis strengthen the idea that exercise programs should be recommended as a strategy to promote driving performance in older adults. The effectiveness of exercise can be higher if there is incorporation of elements that stimulate energetic capabilities and also perceptive-cognitive abilities. When prescribing exercise for older drivers, the design of the intervention program should be supported based on the *similarity of the cognitive processes hypothesis*, which proposes that the transfer of learning occurs primarily because of similarities between the amount and types of cognitive processes required by the performance situations (Magill, 2003). Thus, like it is shown in the present thesis, the transfer of learning between exercise and driving is viable.

It is suggested for future studies to examine whether exercise, in addition to its potential to improve specific driving-related abilities and driving performance, is also effective in preventing road traffic crashes involving older drivers. Longitudinal data are therefore necessary.

Implications for exercise programs for older adults and related investigation

Given that cognitive functioning is closely associated with driving, the analysis of relations between PA and cognitive functioning was a constant issue across this thesis. Discussions about the possible mechanisms that underlie the association between PA and driving-related cognitive abilities were recurrent over the diverse studies. Closely related with this issue was the examination of the influence of the type of exercise on some cognitive abilities.

First of all, the research presented in this dissertation suggests that there is an association between PA and cognitive functioning. Moreover, a specific mode of exercise which was designed with the aim of this thesis in mind and based on the hypothesis that physical activities that repeatedly exert mental resources could promote greater functional effects, was successful in improving performance in tasks requiring specific cognitive functions. Finally, it was demonstrated that the practice of sports, particularly those that depend greatly on the time taken to select and respond to stimuli, are capable of enhancing information processing speed of older drivers.

Much research has been focused on the effects of aerobic fitness on measures of cognitive function (American College of Sports Medicine, 1998). Traditionally, gains in cardiovascular fitness have been considered as the main physiological mediator that underlies the cognitive benefits of PA (Chodzko-Zajko & Moore, 1994; van Boxtel, et al., 1997). Due to the preponderance of this *cardiovascular fitness hypothesis* there is a lack of studies concerning the possibility that physical activities exerting large cognitive demands may have an important influence on cognition (Spirduso, 2006). The paradigm of investigation should change in the next years, especially because important meta-analytic studies have failed to obtain strong evidence for the relation between aerobic fitness and cognitive function (Colcombe & Kramer, 2003; Etnier, Nowell, Landers, & Sibley, 2006), indicating that the underlying mediators of this relationship have yet to be fully identified (Etnier, et al., 2006).

The research work presented in this thesis is one of the first scientific efforts to examine the effects of exercise that merge physical and cognitive stimulation, in an instrumental activity of daily living frequently associated with the individual's cognitive functioning. The rationale of this idea was based on the positive associations between PA and cognitive functioning, and on the positive effects of cognitive training (and complexity) or enrichment environments in brain plasticity and behavior. It is important to point out that other studies that have compared the individual and combined effects of physical and mental exercise interventions reported cognitive benefits to be larger with the combined cognitive and aerobic training paradigms (Fabre, Chamari, Mucci, Masse-Biron, & Prefaut, 2002; Oswald, Rupprecht, Gunzelmann, & Tritt, 1996). Given all this data, future work should explore a line of investigation where the focus of attention is on the potential for different exercise programs to mobilize/stimulate a broad range of abilities (i.e., physical, perceptual and cognitive) and, therefore, to produce higher effects on the quality of life of the elderly.

Four studies carried out in this thesis explored in different ways the relationship between exercise and the performance in tasks associated with cognitive functioning. However, measures of aerobic fitness were not collected, making it impossible to conclude if exercise also improved participants' cardiovascular condition. In the future, general measures of physical fitness should be gathered (especially aerobic fitness), and interventions should involve at least one additional sample group engaged in a typical aerobic exercise program. This would make it possible to control for the influence of aerobic fitness in the collected measures.

Nevertheless, there are important indications in the studies conducted in this thesis that some forms of exercise can induce an extra effect in some cognitive variables. In the second experimental study (*Chapter 5*), performance in tasks that are highly dependent on visual attention, information processing speed and multi-task processing, was successfully enhanced, even though the great majority of participants had good PA levels at baseline and approximately half of the them were already engaged in some form of exercise for at least one year. This strengthened the idea that the perceptive and cognitive specificity of the exercise program was the main responsible for the improvements.

Also, the final study conducted for this thesis on the relation between sport participation and driving performance, provided some evidence that the mode of exercise had a major role on the type of cognitive effects achieved. The results showed a clear trend in the majority of measurements toward a hierarchy of performance with tennis players showing the best results, followed by runners and those not engaged in sports. It was clear that the physiological demands associated with the practice of sports, were not the main foundation of the results just mentioned. Thus, although tennis playing is not more physically demanding than running (moreover, the training volume of runners was significantly higher than for tennis players), the fact is that it was associated with the best driving performance results. Probably, the dependence of proficient tennis playing in perceptive-cognitive abilities like information processing speed and visual attentional may be the major exploration for the findings.

Finally, considering that it is possible that changes in cognitive function with age can result from generalized, age-related slowing of information processing speed (Birren & Fisher, 1995) the improvement of this ability may have an important impact in older adults' driving capability but also in other functional abilities (Edwards, et al., 2005). In the future, more research should address this issue and explore whether the practice of specific modes of exercise/sport that simultaneously requires physical effort (e.g., aerobic capability) and mental effort (e.g., planning and working memory) can influence other functional tasks of daily-living.

CONCLUSIONS

The findings presented in the current work, provide important knowledge about the role of physical activity as a strategy to promote driving ability in older drivers.

Physical activity levels are positively correlated with visual attention in older adults. This is of great relevance since visual attention is a central factor in driving, and, as documented in this thesis, is clearly affected by the aging process. In particular, the ability to divide visual attention, which is the visual aspect more closely associated with driving performance in older drivers, benefit from good habits of physical activity.

Driving-related abilities and on-the-road driving tests performance were enhanced with an intervention that used a type of exercise that intended to simultaneously mobilize physical, perceptive and cognitive abilities. Improvements resulting from the exercise intervention took place in measures of visual attention, behavioral speed, and multi-task processing. Positive transfer of learning from the exercise program to the driving task can be obtained with relatively short time periods of intervention (two to three months); it is important that the type of activities included in the exercise programs for older drivers try to target the same cognitive processes that are required in driving.

The practice of sports on a regular basis for several years has the potential to benefit driving performance. Particularly, tennis playing was associated with better speed of behavior during driving than running. Thus, it seems that those sports that are more challenging in attentional skills and whose performance is very dependent on the speed at which information is processed, may have a positive influence in several aspects of the driving task.

Finally, and from a broader perspective, the role of physical activity and exercise for older adults should not be restricted to the promotion of physical fitness, but should also be considered as a means to enhance cognitive functioning. The type of exercise seems to be an important mediator of such positive effects. Literature reviewed about the effects of training and differential experience on the brain and behavior also supports this potential role of physical activity.

REFERENCES

American College of Sports Medicine (1998). Position Stand: Exercise and physical activity for older adults. *Med Sci Sports Exerc, 30*(6), 992-1008.

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clin Psychol Rev, 25*(1), 45-65.

Atkinson, H. H., Rosano, C., Simonsick, E. M., Williamson, J. D., Davis, C., Ambrosius, W. T., et al. (2007). Cognitive function, gait speed decline, and comorbidities: the health, aging and body composition study. *J Gerontol A Biol Sci Med Sci, 62*(8), 844-850.

Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Invest Ophthalmol Vis Sci, 34*(11), 3110-3123.

Ball, K., Roenker, D. L., Wadley, V. G., Edwards, J. D., Roth, D. L., McGwin, G., Jr., et al. (2006). Can high-risk older drivers be identified through performance-based measures in a Department of Motor Vehicles setting? *J Am Geriatr Soc, 54*(1), 77-84.

Birren, J. E., & Fisher, L. M. (1995). Aging and speed of behavior: possible consequences for psychological functioning. *Annu Rev Psychol, 46*, 329-353.

Bixby, W. R., Spalding, T. W., Haufler, A. J., Deeny, S. P., Mahlow, P. T., Zimmerman, J. B., et al. (2007). The unique relation of physical activity to executive function in older men and women. *Med Sci Sports Exerc, 39*(8), 1408-1416.

Ble, A., Volpato, S., Zuliani, G., Guralnik, J. M., Bandinelli, S., Lauretani, F., et al. (2005). Executive function correlates with walking speed in older persons: the InCHIANTI study. *J Am Geriatr Soc, 53*(3), 410-415.

Carlson, M. C., Fried, L. P., Xue, Q. L., Bandeen-Roche, K., Zeger, S. L., & Brandt, J. (1999). Association between executive attention and physical functional performance in community-dwelling older women. *J Gerontol B Psychol Sci Soc Sci, 54*(5), S262-270.

Chodzko-Zajko, W. J., & Moore, K. A. (1994). Physical fitness and cognitive functioning in aging. *Exerc Sport Sci Rev, 22*, 195-220.

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci, 14*(2), 125-130.

Edwards, J. D., Delahunt, P. B., & Mahncke, H. W. (2009). Cognitive speed of processing training delays driving cessation. *J Gerontol A Biol Sci Med Sci, 64*(12), 1262-1267.

Edwards, J. D., Wadley, V. G., Vance, D. E., Wood, K., Roenker, D. L., & Ball, K. K. (2005). The impact of speed of processing training on cognitive and everyday performance. *Aging Ment Health, 9*(3), 262-271.

Etnier, J. (2008). Interrelationships of exercise, mediator variables, and cognition. In W. W. Spirduso, L. W. Poon & Chodzko-Zajko (Eds.), *Exercise and its mediating effects on cognition* (pp. 13-32). Champaign, IL: Human Kinetics.

Etnier, J., Nowell, P., Landers, D., & Sibley, B. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Res Rev, 52*(1), 119-130.

Fabre, C., Chamari, K., Mucci, P., Masse-Biron, J., & Prefaut, C. (2002). Improvement of cognitive function by mental and/or individualized aerobic training in healthy elderly subjects. *Int J Sports Med, 23*(6), 415-421.

Hultsch, D. F., Hertzog, C., Small, B. J., & Dixon, R. A. (1999). Use it or lose it: engaged lifestyle as a buffer of cognitive decline in aging? *Psychol Aging, 14*(2), 245-263.

Johnson, J. K., Lui, L. Y., & Yaffe, K. (2007). Executive function, more than global cognition, predicts functional decline and mortality in elderly women. *J Gerontol A Biol Sci Med Sci, 62*(10), 1134-1141.

Kooijman, C., Brouwer, W. H., Coeckelbergh, T. R., Tant, M. L., Cornelissen, F. W., Bredewoud, R. A., et al. (2004). Compensatory viewing training improves practical fitness to drive of subjects with impaired vision. *Vis Impair Res, 6*(1), 1-27.

Kramer, A. F., Colcombe, S. J., McAuley, E., Eriksen, K. I., Scalf, P., Jerome, G. J., et al. (2003). Enhancing brain and cognitive function of older adults through fitness training. *J Mol Neurosci, 20*(3), 213-221.

Kramer, A. F., Colcombe, S. J., McAuley, E., Scalf, P. E., & Erickson, K. I. (2005). Fitness, aging and neurocognitive function. *Neurobiol Aging, 26 Suppl 1*, 124-127.

Kua, A., Korner-Bitensky, N., Desrosiers, J., Man-Son-Hing, M., & Marshall, S. (2007). Older driver retraining: a systematic review of evidence of effectiveness. *J Safety Res, 38*(1), 81-90.

Magill, R. (2003). *Motor Learning and control, concepts and applications* (Seventh ed.). New York: McGraw-Hill.

Manser, M. P., & Hancock, P. A. (1996). Influence of approach angle on estimates of Time to-Contact. *Ecol Psychol, 8*(1), 71-99.

Marottoli, R. A., Cooney, L. M., Jr., Wagner, R., Doucette, J., & Tinetti, M. E. (1994). Predictors of automobile crashes and moving violations among elderly drivers. *Ann Intern Med, 121*(11), 842-846.

Marottoli, R. A., Ness, P. H., Araujo, K. L., Iannone, L. P., Acampora, D., Charpentier, P., et al. (2007). A randomized trial of an education program to enhance older driver performance. *J Gerontol A Biol Sci Med Sci, 62*(10), 1113-1119.

Ostrow, A. C., Shaffron, P., & McPherson, K. (1992). The effects of a joint range-of-motion physical fitness training program on the automobile driving skills of older adults. *J Safety Res, 23*, 207-219.

Oswald, W. D., Rupprecht, R., Gunzelmann, T., & Tritt, K. (1996). The SIMA-project: effects of 1 year cognitive and psychomotor training on cognitive abilities of the elderly. *Behav Brain Res, 78*(1), 67-72.

Owsley, C., Ball, K., McGwin, G., Jr., Sloane, M. E., Roenker, D. L., White, M. F., et al. (1998). Visual processing impairment and risk of motor vehicle crash among older adults. *JAMA, 279*(14), 1083-1088.

Owsley, C., Sloane, M., McGwin, G., & Ball, K. (2002). Timed instrumental activities of daily living tasks: Relationship to cognitive function and everyday performance assessments in older adults. *Gerontology, 48*, 254-265.

Roenker, D. L., Cissell, G. M., Ball, K. K., Wadley, V. G., & Edwards, J. D. (2003). Speed-of-processing and driving simulator training result in improved driving performance. *Hum Factors, 45*(2), 218-233.

Salthouse, T. (2006). Mental Exercise and Mental Aging. Evaluating the Validity of the ‘‘Use It or Lose It’’ Hypothesis. *Perspectives on Psychological Science, 1*(1), 68-87.

Spirduso, W. W. (2006). Issues of aging, physical activity, cognition and putative mechanisms for a relationship: a discussion. In L. W. Poon, W. Chodzko-Zajko & P. D. Tomporowski (Eds.), *Active living, Cognitive Functioning and Aging* (pp. 187-195). Champaign: Human Kinetics.

Swaab, D. F., Dubelaar, E. J., Hofman, M. A., Scherder, E. J., van Someren, E. J., & Verwer, R. W. (2002). Brain aging and Alzheimer's disease; use it or lose it. *Prog Brain Res, 138*, 343-373.

van Boxtel, M. P., Paas, F. G., Houx, P. J., Adam, J. J., Teeken, J. C., & Jolles, J. (1997). Aerobic capacity and cognitive performance in a cross-sectional aging study. *Med Sci Sports Exerc, 29*(10), 1357-1365.

Vance, D. E., Roenker, D. L., Cissell, G. M., Edwards, J. D., Wadley, V. G., & Ball, K. K. (2006). Predictors of driving exposure and avoidance in a field study of older drivers from the state of Maryland. *Accid Anal Prev, 38*(4), 823-831.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychol Bull, 120*(2), 272-292.

Whelihan, W. M., DiCarlo, M. A., & Paul, R. H. (2005). The relationship of neuropsychological functioning to driving competence in older persons with early cognitive decline. *Arch Clin Neuropsychol, 20*(2), 217-228.